

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NASA CR-114338

Available to the Public

TECHNOLOGY ASSESSMENT OF
ADVANCED GENERAL AVIATION AIRCRAFT

SUMMARY REPORT

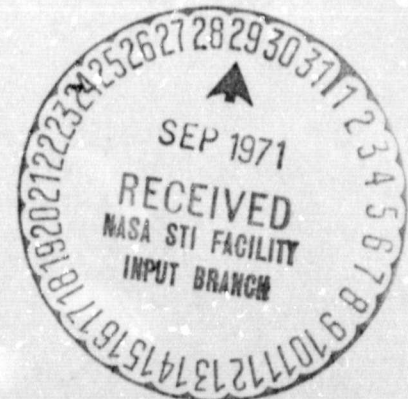
June, 1971

Distribution of this report is provided in the interest of information exchange. Responsibility for the contents resides in the author or organization that prepared it.

Prepared under Contract No. NAS2-5972 by
C. H. Hurkamp, W. M. Johnston, and J. H. Wilson
The Advanced Concepts Department
LOCKHEED-GEORGIA COMPANY
Marietta, Georgia

FACILITY FORM 602	N71-35217	
	(ACCESSION NUMBER)	(THRU)
	57	H3
	(PAGES)	(CODE)
	CR-114339	02
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

Advanced Concepts and Missions Division
Office of Advanced Research and Technology
National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California



NASA CR-114338

TECHNOLOGY ASSESSMENT OF
ADVANCED GENERAL AVIATION AIRCRAFT

SUMMARY REPORT

June, 1971

Distribution of this report is provided in the interest of information exchange. Responsibility for the contents resides in the author or organization that prepared it.

Prepared under Contract No. NAS2-5972 by
C. H. Hurkamp, W. M. Johnston, and J. H. Wilson
The Advanced Concepts Department
LOCKHEED-GEORGIA COMPANY
Marietta, Georgia

FOR

Advanced Concepts and Missions Division
Office of Advanced Research and Technology
National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

FOREWORD

Contract NAS2-5972 between the National Aeronautics and Space Administration and the Lockheed-Georgia Company, effective 15 June 1970, provided for the assessment of the impact of advanced technology applicable to general aviation aircraft for the 1985 time frame and for recommendations for additional research areas which may increase the safety, utility, and economy of general aviation.

The work reported herein was sponsored by the Advanced Concepts and Missions Division of the Office of Advanced Research and Technology, Mr. Thomas L. Galloway, NASA study monitor.

The work at the Lockheed-Georgia Company under this contract was the responsibility of the Chief Preliminary Design Engineer, Dr. W. C. J. Garrard, and of the Advanced Concepts Department, Mr. R. H. Lange, Manager.

This report summarizes the work performed in fulfillment of the above contract.

TABLE OF CONTENTS

<u>Section No.</u>	<u>Title</u>	<u>Page No.</u>
1.1	Introduction	1-1
1.2	Acknowledgements	1-2
1.3	Scope of Study	1-3
1.4	Requirement & Constraints	1-4
1.5	Technology Investigation	1-5
1.5.1	Aerodynamic Design	1-5
1.5.2	Propulsion Technology	1-7
1.5.3	Structure and Materials	1-10
1.5.4	Avionics, Instrumentation and Flight Control	1-11
1.5.5	Landing Gear	1-12
1.5.6	Functional Subsystems	1-13
1.5.7	Utility and Convenience Features	1-14
1.5.8	Safety Considerations	1-14
1.5.9	VTOL Technology	1-15
1.6	Selection of Baseline Designs	1-16
1.7	Parametric Analysis	1-19
1.7.1	Methodology	1-19
1.7.2	Results and Baseline Configurations	1-22
1.8	Sensitivity Analyses	1-28
1.8.1	General Procedure	1-28
1.8.2	Advanced Technology Baseline Design	1-28
1.8.3	Alternate Configurations	1-32
1.8.4	Advanced Avionics and Subsystems	1-33
1.8.5	Performance Variables	1-37
1.8.6	Increased Production	1-40
1.8.7	Sensitivity Summary	1-41
1.9	Recommended Configurations	1-42
1.9.1	Category I	1-42
1.9.2	Category II	1-43
1.9.3	Category III	1-44
1.9.4	Category IV	1-46
1.10	Projection of General Aviation Use Potential	1-47
1.10.1	Price/Quantity Relationship	1-47
1.10.2	Growth Constraints	1-48
1.11	Conclusions	1-48
1.11.1	Specific Conclusions	1-48
1.11.2	General Conclusions	1-49
1.12	Recommendations	1-50
1.12.1	Aircraft Research and Development	1-50
1.12.2	Propulsion Research and Development	1-50
1.12.3	General Aviation Non-Technical Constraint Studies	1-51
	References	1-51

FIGURE INDEX

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1.3.1	Study Plan	1-3
1.4.1	Summary of Baseline Design Requirements	1-4
1.5.1	Engine Matrix	1-7
1.5.2	Comparative Propulsor Performance	1-8
1.5.3	Propeller R.P.M. for Seventy-Five PNdb Noise Level	1-9
1.5.4	Specific Tensile Strength vs. Specific Tensile Modulus of Composites	1-9
1.5.5	Systems Classification	1-10
1.5.6	Soil Strength Required to Support Overpressure	1-11
1.5.7	ACIS Typical Trunk Plenum	1-12
1.5.8	Vertical Lift Capability vs. Disc. Loading	1-13
1.6.1	Category I Candidates	1-15
1.6.2	Category II Candidates	1-16
1.6.3	Category III Propeller Candidates	1-17
1.6.4	Category IV Candidates	1-18
1.7.1	Parametric Flow Diagram	1-18
1.7.2	Price Trend of General Aviation Aircraft with Weight-Speed Product	1-19
1.7.3	Operating Cost Factors Summary	1-20
1.7.4	Aircraft - Mile Cost Trend with Utilization	1-21
1.7.5	Category I Parametric Analysis Results	1-21
1.7.6	General Arrangement: Category I Baseline Aircraft	1-22
1.7.7	Category II Parametric Analysis Results	1-23
1.7.8	General Arrangement Category II Baseline Aircraft	1-24
1.7.9	Category III Parametric Analysis Results	1-25
1.7.10	General Arrangement Category III Baseline Aircraft	1-26
1.7.11	Category IV Parametric Analysis Results	1-26
1.7.12	General Arrangement Category IV Baseline Aircraft	1-27
1.8.1	Sensitivity Analysis Procedure	1-27
1.8.2	Effect of Advanced Propulsion	1-28
1.8.3	Effect of Advanced Materials	1-28
1.8.4	Combined Effect of Advanced Propulsion and Materials	1-29
1.8.5	General Arrangement: Category I Advanced Technology Aircraft	1-29
1.8.6	General Arrangement: Category II Advanced Technology Aircraft	1-30
1.8.7	General Arrangement: Category III Advanced Technology Aircraft	1-30
1.8.8	General Arrangement: Category IV Advanced Technology Aircraft	1-31
1.8.9	Category I Comparison: Foldable Wings and Roadability	1-31
1.8.10	Category II Comparison: Fixed Wings vs. Autogyro	1-32

FIGURE INDEX

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1.8.11	General Arrangement Category III Turbofan Aircraft	1-34
1.8.12	Category III Comparison: Propellers vs. Turbofan	1-34
1.8.14	Effect of Advanced Avionics and Automatic Flight Controls	1-35
1.8.15	Effect of Extra Safety Provisions	1-36
1.8.16	Effect of Pressurization and High Altitude Cruise	1-36
1.8.17	Effect of Noise Level on Price	1-37
1.8.18	Effect of Field Length on Price	1-37
1.8.19	Effect of Cruise Speed on Price	1-38
1.8.20	Effect of Cruise Speed on Operating Cost	1-38
1.8.21	Effect of Cruise Range on Price	1-38
1.8.22	Effect of Seating Capacity on Price and Seat - Mile Cost	1-39
1.8.23	Effect of Yearly Production Rate on Price	1-40
1.8.24	Effect of Technology and Noise Levels on Price vs. Weight - Speed Product	1-41
1.8.25	Effect of Added Provisions on Price vs. Weight - Speed Product	1-41
1.9.1	General Arrangement Category I Recommended Configuration	1-42
1.9.2	Comparison Between Recommended and Baseline Configurations, Category I	1-42
1.9.3	General Arrangement Category II Recommended Configuration	1-43
1.9.4	Comparison Between Recommended and Baseline Configurations, Category II	1-43
1.9.5	General Arrangement Category III Recommended Configuration	1-44
1.9.6	Comparison Between Recommended and Baseline Configurations, Category III	1-45
1.9.7	Comparison Between Recommended and Baseline Configurations, Category IV	1-46
1.10.1	Past and Projected General Aviation Aircraft Deliveries Per Year	1-47
1.10.2	Price Classifications of General Aviation Aircraft Delivered in 1969 and Their Relationship to Categories I, II, and III	1-47
1.12.1	Recommended Aircraft - R&D Areas	1-50
1.12.2	Recommended Propulsion Avionics - R&D Areas	1-50
1.12.3	General Aviation Non-Technical Constraint Studies	1-57

1.1 Introduction

NASA studies of possible short-haul transportation have shown that general aviation has the potential of performing an increasingly important role in the national transportation system (Reference 1.1). In order to realize this potential fully, the cost, performance, and operational characteristics of this class of aircraft must be improved. NASA, through in-house and contractual studies, is attempting to identify critical technology areas where additional research may increase the safety, utility, and economy of general aviation. (See Reference 1.2.) The intent of the present study is to assess the impact of advanced technology applicable to general aviation aircraft for the 1985 time frame. An important facet of the study is to relate the influence of advanced technology and new design philosophies on the cost, performance, and operational capabilities of this class of aircraft. The four categories include conventional, STOL and V/STOL performance in 4 to 9 place aircraft, with helicopters included in the study. The study procedure consists of:

- (a) establishing an optimized design configuration in each category, based on present technology;
- (b) investigating and pinpointing the most promising areas of applicable technology;
- (c) applying the selected advanced technology to each of the present technology designs;
- (d) assessing the results and making recommendations for additional research.

The areas of advanced technology include those of aerodynamics, propulsion, structural materials, avionics, flight safety, automatic control, noise and emission abatement. These are assessed individually and in combination by means of a computerized analysis. The recommended combinations are then studied to determine their potential impact on the overall transportation system, after which the areas of technical support are recommended. This report comprises a summary of the study program. A more complete treatment is contained in Reference 1.3, the Final Report.

It should be emphasized that the final results of the study, in the form of recommended configurations in each of the four categories specified by NASA, indicate long range potential and not predictions. In order to help develop this potential, extensive government support is required in the areas of technology research and development, the expansion of small airfields, pilot training assistance and other educational programs.

1.2 Acknowledgements

The Lockheed-Georgia Company study team was led by C. H. Hurkamp, under the direction of R. H. Lange, Manager, Advanced Concepts Department. The study team comprised the following members:

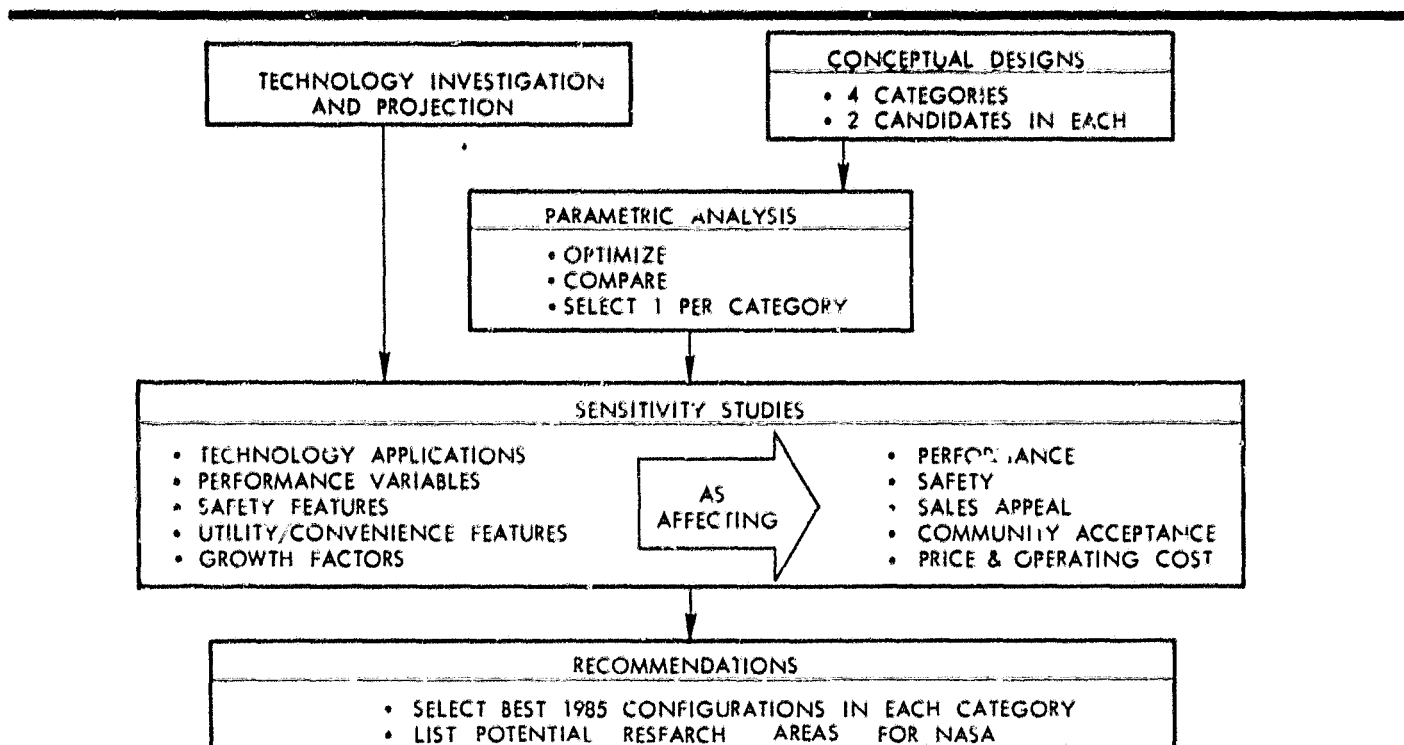
W. M. Johnston	Aerodynamic Analysis
H. E. Schmitt	Propulsion Analysis
D. F. Glover, Jr.	Weight Analysis
J. H. Wilson	Cost Analysis
B. E. Montgomery	Avionics Technology
J. M. Eaton.	Conceptual Design
N. R. Daigle	Computer Programming
R. Vick.	Computer Programming
A. W. Mooney	Program Consultant

Advisory service was rendered by K. H. Wilson, Reliability Division Engineer, Lockheed-Georgia Company, A. R. Yackle, Assistant Division Engineer (Rotary Wing), Lockheed-California Company, and W. M. Hawkins, Vice-President, Science & Engineering, Lockheed Aircraft Corporation. The investigators wish to acknowledge, with thanks, direct contributions received from the following individuals and organizations:

Mr. Carl Rohrbach, Hamilton Standard Division, United Aircraft Corp.
Mr. David Biermann, Hartzell Propeller Company
Mr. M. K. Schleich, McCauley Industrial Corporation
Dr. R. S. Ross, Goodyear Aerospace Corporation
Messrs. R. S. Kelso and George Cash, Cornell Aeronautical Laboratory
Mr. J. H. Simmons, Piper Aircraft Corp., Vero Beach, Florida
Mr. D. R. Ellis (Mgr., Flying Qualities Research) Princeton University
Mr. E. R. Hinz, The Aerospace Corporation
Mr. R. B. Lightfoot, Sikorsky Aircraft Division, United Aircraft Corporation
Mr. R. L. Lichten, Bell Helicopter Company
Messrs H. Allen and R. Leisenring, Curtiss-Wright Corporation
Mr. H. D. Cox, Teledyne Continental Motors
Messrs. R. L. Gummings and H. Gold, Lewis Research Center, NASA
Messrs. Schenkly, Griffith, Paul and Roberts; Lockheed Missiles and Space Co.
Dr. K. H. Digges, Air Force Flight Dynamics Laboratory
Mr. J. L. Churchill, Collins Radio Company
Mr. V. J. Kayne, Aircraft Owners and Pilots Association
Mr. J. W. Bail, Narco Avionics
Mr. A. R. Applegarth, Aradar Corp.

The investigators also wish to acknowledge their appreciation of the assistance rendered by the NASA Study Monitor, Mr. T. L. Galloway, during the entire study and in the preparation of this report.

FIGURE 1.3.1 STUDY PLAN



1.3 Scope of Study

The study follows the guidelines and constraints of paragraphs 1.4 and 1.5 of the Statement of Work in Reference 1.4. This document, which formed part of the RFP for this study, was interpreted by the Contractor in his Technical Proposal, Lockheed-Georgia Company Report ETP 943. The overall scope is illustrated in the Study Flow Diagram, Figure 1.3.1.

The first step of establishing requirements is to identify the constraints imposed by the RFP along with FAA requirements and any modifications agreed upon by the contractor and NASA. The second step is the identification of the projected applicable technology, in each of the areas listed, by specialized engineering personnel in each discipline and with the aid of published reference data and consultation with cognizant representatives of NASA, Lockheed and other organizations in the fields of airframe, engine, materials, avionics and applicable subsystems. In the third step, the most appropriate lines of technological development are selected for application to the sensitivity analysis. The fourth step is that in which two or more candidate configurations are investigated for each of the four specified categories. These configurations are then optimized by the use of parametric programs, using initial and operating cost as criteria. Present state-of-the-art is applied so that a base can be established for advanced technology sensitivity analysis.

In the fifth step, the candidate configurations within each category are compared, and one or more out of each is selected for sensitivity studies. The sixth step consists of applying variable characteristics to the selected configurations to determine the effectiveness of each variable toward improving the desired characteristics. These variables fall under five headings: Technology, Safety, Environmental Performance and Growth. For each technology variable the future state-of-the-art is related to that of the present, so that its effect on the characteristics listed can be determined. The results of the sensitivity studies are then examined to determine optimum combinations and to recommend a selected future configuration in each category.

Finally, the last step fulfills the principal purpose of the study by defining the recommended areas of study, research and development recommended to assist in promoting technology which will enhance the future growth of general aviation.

FIGURE 1.4.1 SUMMARY OF BASELINE DESIGN REQUIREMENTS

<u>CATEGORY</u>	<u>I</u>	<u>II</u>	<u>III</u>	<u>IV</u>
CRITICAL FIELD LENGTH (FT.)	1000	500	1500	VTOL
RANGE (STAT. MILES)	500	500	1500	500
CRUISE SPEED (KNOTS)	130	200	250	150
MIN. NO. OF SEATS	4	4	6	4

COMMON REQUIREMENTS

EXTERIOR NOISE LEVEL	75 PNdb AT 500 FT.
WEIGHT ALLOWANCE PER SEAT	220 LBS. (INCLUDING BAGGAGE)
FUEL RESERVE	45 MIN.

1.4 Requirements and Constraints

Constraints and guidelines for the study were imposed by NASA in the Specification referred to in Section 1.3 and are briefly summarized below:

- ° Use advanced technology applicable to the 1985 time period (this was applied in the sensitivity analyses to the baseline configurations which reflect present technology).
- ° Apply the results of previous and current applicable studies.
- ° Apply FAA regulations, point out restrictions or inadequacies, or use industry-accepted criteria.
- ° Limit the external noise level to 75 PNdb at 500 ft.
- ° Assess the effect of annual production rate on aircraft cost.
- ° Express costs in 1969 dollars (1970 was adopted).
- ° Meet performance requirements with aircraft fully loaded (220 lbs per passenger including baggage.)
- ° Meet specified extra safety requirements (assessed separately in the sensitivity analyses).
- ° Calculate operating cost for three levels of yearly utilization (100, 300 and 500 hours)

Table 1.4.1 shows the minimum performance requirements specified for each category of aircraft investigated. These requirements were subjected to sensitivity analyses, which are reported in Section 1.8.

1.5 Technology Investigation

This portion of the study covers an examination of present and emerging technology in the disciplines governing the design of aircraft in each of the four categories. They include aerodynamics, propulsion, structure and materials, avionics, landing gear, functional subsystems, safety techniques, utility and convenience features, and VTOL technology.

1.5.1 Aerodynamic Design

Aerodynamic technology investigation covers the areas of high lift systems, drag configuration and stability and control considerations, which will be discussed in that order.

Appropriate non-augmented high lift systems, resulting from NASA research, were investigated for application to the four aircraft categories of this study. Two types were selected for parametric analysis:

- o The single slotted flap, identified as 2h in NACA TR 664, appropriate for airplanes in Categories I and III.
- o The double slotted type flap reported in NACA TR 723, appropriate for airplanes in Category II, in combination with dropped ailerons of similar shape to that of the single slotted flap.

Augmented systems were not considered because of their complication and attendant high cost. They would only be appropriate to the STOL airplanes in Category II. These, however, are single engined, and minimum flight speed would have to be based on the power-off condition.

No new technology is available for the application of drag reduction, other than that of applying the tried and true principles of good aerodynamic design. This includes proper streamlining of the fuselage and the avoidance of bad interference effects at the junctures of principal components, such as the wing-fuselage intersection.

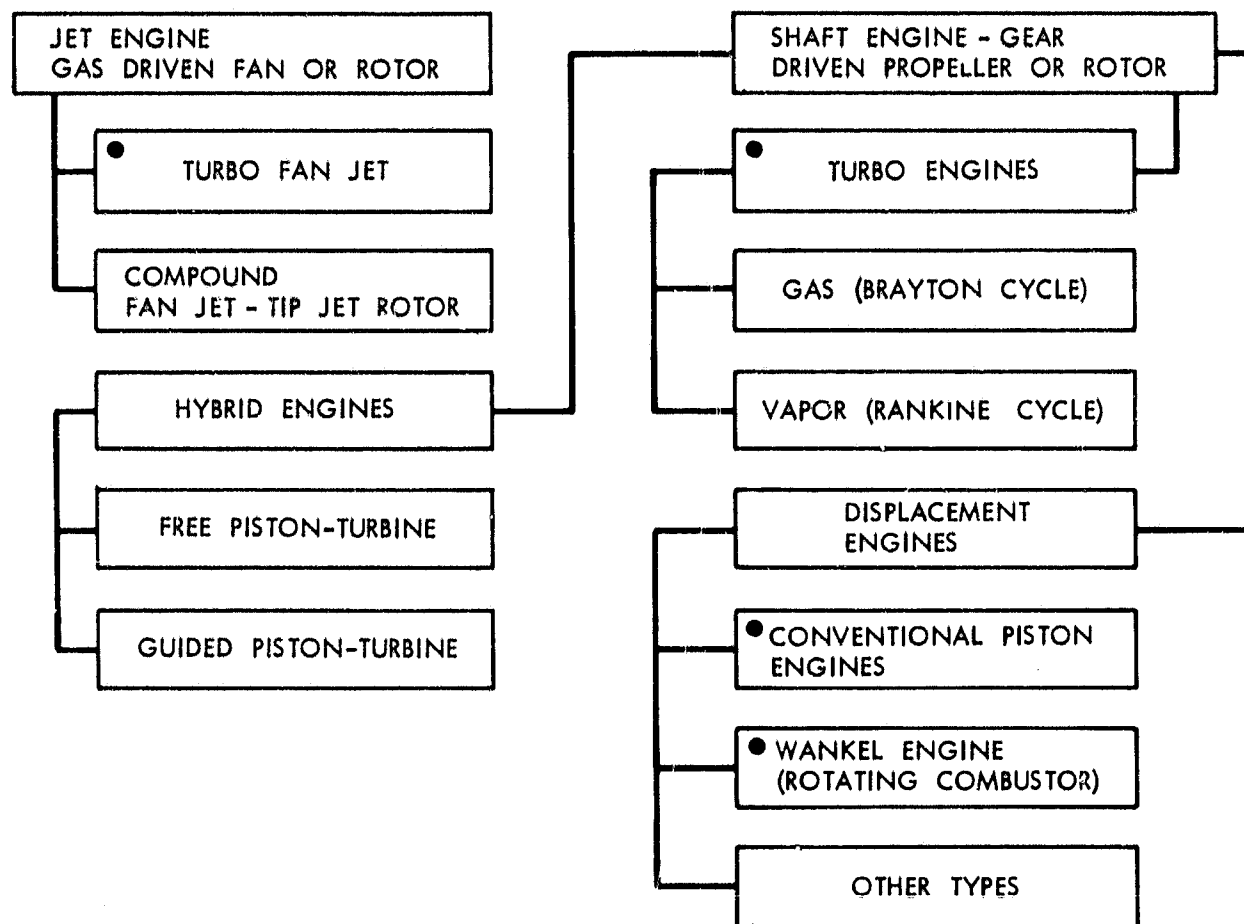
Pusher propeller configurations are included in the Category I and II applications. Previous examples in the general aviation industry have proven to result in abnormally high drag, due to maintaining a short length of fuselage between the full-width cross-section and the propeller spinner. The examples investigated in this study employ extension shafting between the engine and propeller. The fuselage itself is faired to a two-dimensional wedge in the vertical plane, with a superimposed streamlined body, connecting the air induction scoop and the propeller spinner faired in the horizontal plane. This method is believed to result in drag comparable to that of a well-designed tractor propeller airplane, since it is not subject to slipstream impingement.

Both fixed and retractable landing gear were investigated for Category I, while the other three categories use retractable gear.

A brief investigation was made of longitudinal stability and control characteristics to determine the most appropriate horizontal tail configuration and center of gravity limits. It was concluded that the combination of a variable incidence stabilizer with a single slotted elevator requires the lowest ratio of horizontal tail area to wing area, being about half that of the conventional fixed stabilizer with an unslotted elevator. The combination of a "flying tail" with an anti-boost tab is somewhat better than conventional practice, but is not as effective as the recommended configuration and has other disadvantages, such as increased susceptibility to flutter and lowered level of safety in the event of a failure of the longitudinal control system. With a pusher propeller installation, the rearmost C.G. position must be well forward along the M.A.C. in order to minimize tail size. A usable C.G. travel of 15% of the M.A.C. is recommended.

The aerodynamic inputs to the computer are the zero lift drag, high lift characteristics, and proper induced drag constants. The zero lift drag is based on flight cruise speed, wing and tail thickness ratios, fuselage geometry, and special configuration characteristics. The flap characteristics are based on NASA data, and a wing efficiency factor of 0.8 is used for determination of induced drag.

FIGURE 1.5.1 ENGINE MATRIX

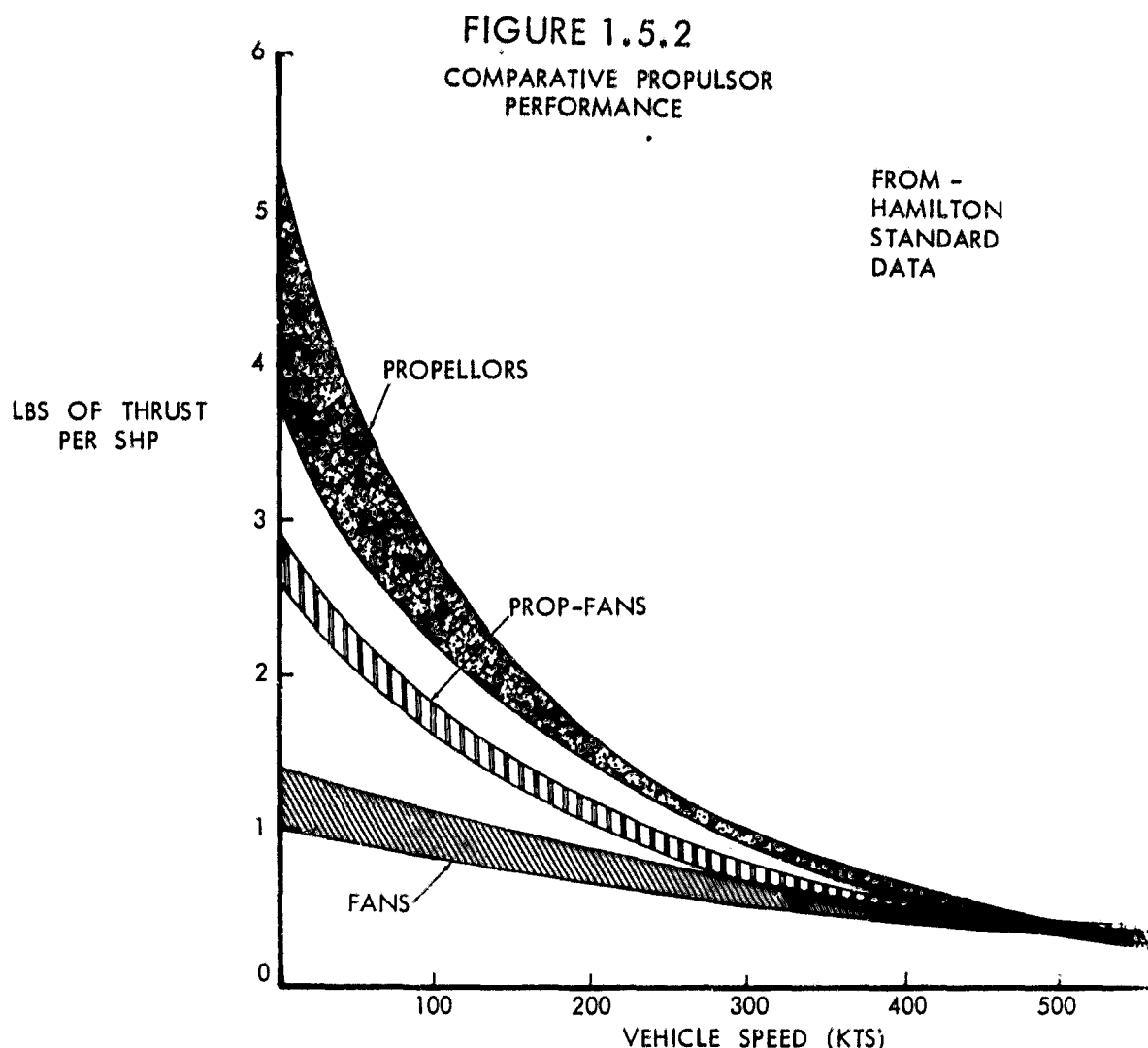


1.5.2 Propulsion Technology

The investigation of this subject is divided into the following categories:

- o Engine Types
- o Propulsors
- o Propeller Technology
- o Engine Emission of Pollutants
- o Propulsion Noise

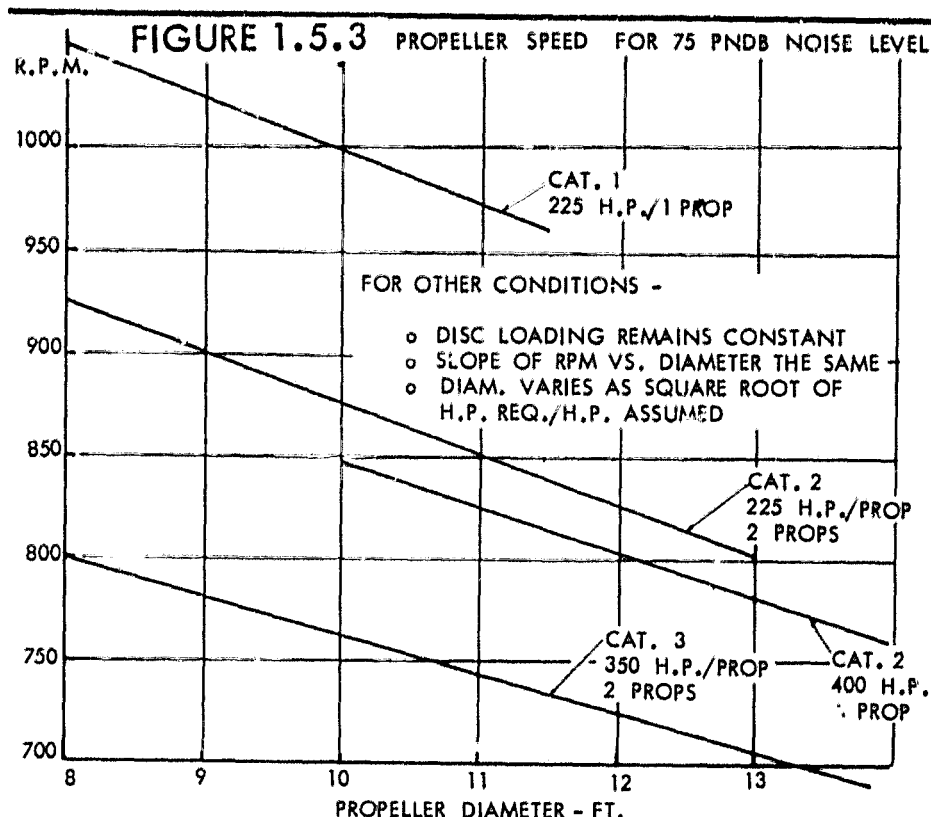
The investigation scope of engine types covers those marked with black circles in the engine matrix diagram of Figure 1.5.1. The present level of technology indicates the superiority of the reciprocating engine for Category I aircraft with the turboshaft engine becoming a strong competitor in the other three categories. Looking ahead to 1985, however, there appears to be a great potential for the rotating combustion engine, which has already appeared on the automotive scene and has been experimentally tested in aircraft.



Looking at propulsor technology, the propeller appears to be the most efficient type in the cruise speed range of 130 to 250 knots of interest to this study. Nevertheless, the turbofan engine is competitive in Category III and the multi-blade, shrouded propeller (termed "prop-fan") is another strong possibility. Figure 1.5.2 shows the relative effectiveness of propellers, prop-fans and turbofans in terms of thrust per horsepower at various speeds. However, since high cruise speed is considered a desirable asset for business aircraft, the turbofan has been evaluated against the rotating combustion engine/propeller combination in Category III.

The emission of pollutants is not nearly as serious in aircraft engines as in automotive engines. Aircraft engines contribute less than 2 percent of the total emission pollution. Normal cruise at relatively low fuel-air ratio results in low carbon monoxide emission. The only operating conditions in which carbon monoxide would be released are high power and idle operation, and this condition can be alleviated by the use of fuel injection. It is expected, however, that some special provision may eventually have to be made to reduce the amount of nitrogen compounds in exhaust gas during the next decade, but much work is being done on this problem by automotive companies, and the aircraft engine manufacturers could use the same techniques.

Technological advances in the propeller field have so far been restricted to propellers for large, high performance airplanes. They include development of the fiberglass/steel spar blade, integral reduction gearing and variable camber. Not only has the ratio of weight-to-shaft horsepower been steadily decreasing, but considerable progress has been made in providing for fail-safe, easily maintained hardware. Hamilton-Standard's NASA-sponsored study (Reference 1.5) outlines several interesting approaches to simplified light-weight, low-cost propeller design appropriate to general aviation aircraft.

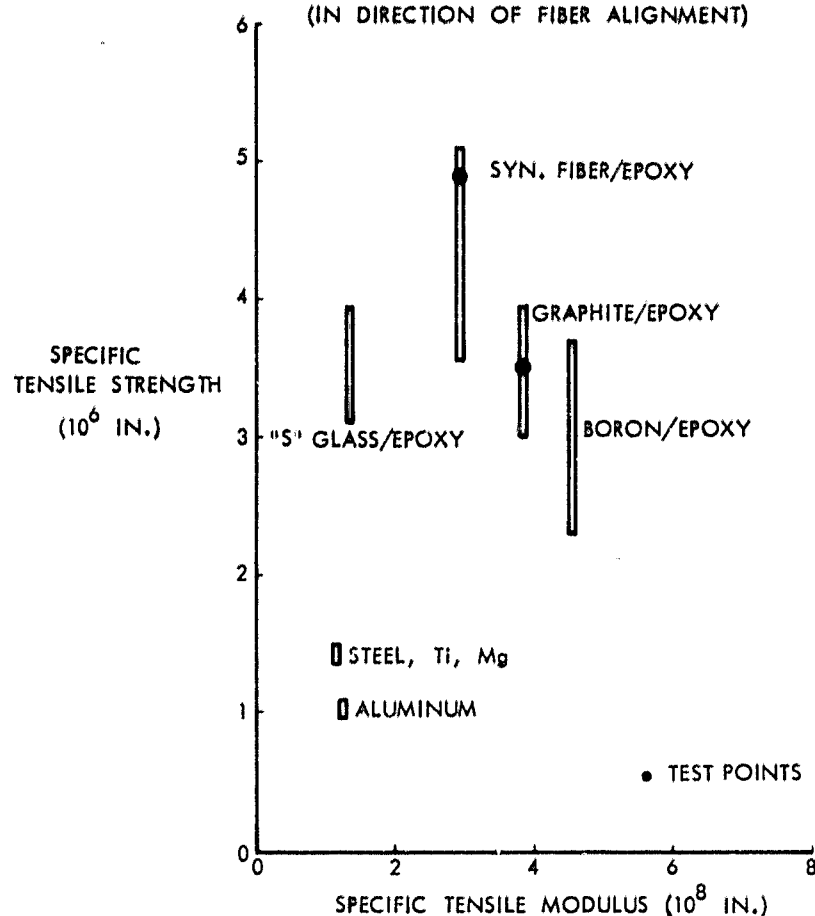


The noise level of piston and rotating combustion engines can be quieted below the propeller noise level by reliable techniques. Turbofan engines are much more difficult and the practical lower limit appears to be about 85 PNdB at 500 ft. A very considerable weight and cost penalty would accrue as a result of reducing the noise level below this value.

Considerable study has been given, in the helicopter field, to the reduction of rotor noise. Effective techniques have included operation at tip speeds below 550 ft/sec, use of sound-absorbing materials in the engine compartment and application of trapezoidal or sweptback blade tips. This over-all treatment is enough to assure meeting the study requirement of 75 PNdB at 500 ft, which is particularly appropriate to helicopter operation in densely populated areas.

The interrelation of propeller performance with noise level has received considerable attention in this study. Variations of RPM with propeller diameter for 75 PNdB noise level at typical powers for the first three categories of airplanes are shown in Figure 1.5.3. In Categories I, II, and III, it has been found feasible to install large diameter, slow-turning propellers which not only have a high static thrust-to-horsepower ratio but also a high level of efficiency in cruise flight. The diameters required for Category I are not unreasonably large, but grow increasingly larger as the power requirements for Categories II and III increase. Propellers which meet the 75 PNdB noise level in Category III are from 15 to 17 ft in diameter and require serious compromises in the design of the airplane. The methodology used in this study was developed by Hamilton Standard in the previously mentioned study for NASA which was directed entirely at general aviation use. Quiet propeller operation has been successfully demonstrated, with the Lockheed Missiles and Space Company "Q-Star" and their Army-sponsored YO-3A airplanes.

FIGURE 1.5.4 SPECIFIC TENSILE STRENGTH
VS.
SPECIFIC TENSILE MODULUS OF COMPOSITES
(IN DIRECTION OF FIBER ALIGNMENT)



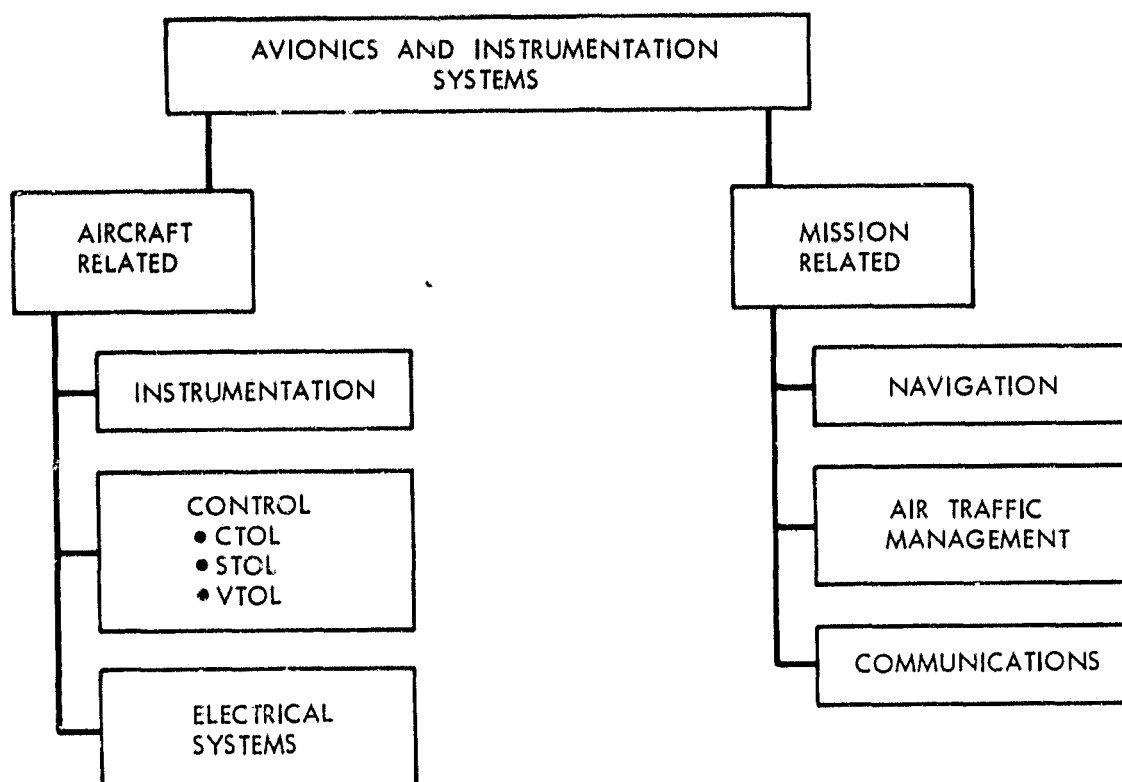
1.5.3 Structure and Materials

The application of advanced materials, structural design, and manufacturing techniques to general aviation aircraft has been investigated by San Diego Aircraft Engineering, Inc., in a previous NASA study (Reference 1.2).

New structural material applicable to general aviation use include previously used and emerging composites. Glass fibers in a resin matrix have had limited aircraft employment to date, but this material is expected to be used with increasing frequency as new fabrication processes come into being. Much higher strength-to-weight composites, such as graphite, boron and a new synthetic fiber, all used in an epoxy matrix, with desired directional alignment, are in the research and development stage. They are expected to become available for general aviation use in the 1985 time period when the cost of these materials drop to reasonable levels. Figure 1.5.4 shows a comparison between the specific tensile stress vs specific modulus characteristics of composite materials and metals.

Design techniques with composite materials presently utilize sandwich construction to a great extent. A lightweight core material, such as fiberglass or paper honeycomb, or foamed plastic, is used between laminae of pre-impregnated fibers. Complete structural components can be integrally bonded, dispensing altogether with the use of fasteners. Short fiber-reinforced, injection molded parts can be designed as primary structural components by the use of advanced tooling methods. Eventually, large structural components, such as wing and fuselage halves, can be integrally molded in one piece. Such processes should have a profound effect in reducing the manufacturing cost and weight of general aviation aircraft.

FIGURE 1.5.5. SYSTEMS CLASSIFICATION



1.5.4 Avionics, Instrumentation and Flight Control

The ultimate emergence of general aviation as a principal mode of transportation depends, to a major extent, on the development of guidance in the airspace. Flying without adequate guidance is equivalent to driving on unmarked highways. The National Airspace System, under the control of the FAA, is an assembly of equipment, installations, people and procedures set up to control mainly the movement of all aircraft operating under IFR. It has been troubled by the increasing density of air traffic, which has outstripped the availability of facilities and manpower. A new system of Intermittent Positive Control has been recommended to alleviate the situation. While a major of general aviation pilots fly under VFR conditions, extended utilization, particularly by business operators, must include increasing operation under IFR.

Figure 1.5.5 shows the division of aircraft avionics and instrumentation into the categories of aircraft-related and mission-related systems. The former are basic to the aircraft and independent of its use. Included in this category are the artificial horizon, directional gyro, compass, flight director and integrated displays. The last item is being developed for cathode ray tube presentation, which may someday be in the price range of general aviation users. Automatic flight control systems are aircraft-related and particularly useful in VTOL and STOL operations. The requirement for a 3-axis autopilot and a computer, again, result in high-priced installations.

Mission-related systems include navigation aids, air traffic management and communication systems. The VORTAC system will continue to be used for short range navigation, but its capability will be improved by the introduction of area navigation. Other Nav-aid systems which might be used in the future by general aviation include Loran, Omega and inertial guidance. ADF will play a decreasing role domestically. VHF voice communication is expected to continue in use and eventually be augmented by a data link system. The Air Traffic Control Radar Beacon System has been adopted for identification and altitude

determination, requiring the use of transponders in aircraft which operate in congested traffic areas. Another up-coming requirement is that of crash locator beacons. Highly sophisticated equipment, which is and will be beyond the price range of most operators, includes weather radar, collision avoidance systems and clear air turbulence detection systems.

All avionics equipment for general aviation use must provide the elements of safety, reliability, maintainability and economy. Redundant circuitry can be used to maintain fail-operational capability. Federal standards should govern the reliability of equipment and it should be easily removable and replaceable for maintenance. The principal barrier is economy. The high price constraint may be gradually diminished by increase in demand for advanced equipment and standardization. Typical avionics "packages" were selected for the baseline aircraft. More highly sophisticated equipment, including that required for fully automatic flight control, were evaluated in the sensitivity analyses.

It is expected that, in the next 15 years, the unit weight and cost of avionics having a particular capability would be reduced, based on 1970 dollars. However, there is an increased capability requirement as traffic becomes more dense, and more aircraft have all-weather capability. As a consequence, it is expected that the typical 1985 avionics package would have approximately the same weight and cost as the 1970 package, but would have much increased capability.

1.5.5 Landing Gear

Several requirements must be fulfilled in order to provide an efficient landing gear for general aviation aircraft. They embrace the ground contact elements, the energy absorption systems, ground handling control, and the minimization of aerodynamic drag. Two general types of landing gear are suitable for general aviation: the tricycle wheel gear and the air cushion landing system (ACLS). The choice between the two depends to a major extent on the type of terrain from which the aircraft will be operated.

Figure 1.5.6 presents a plot of the ground pressure exerted by several types of vehicles against the required soil strength expressed in terms of California

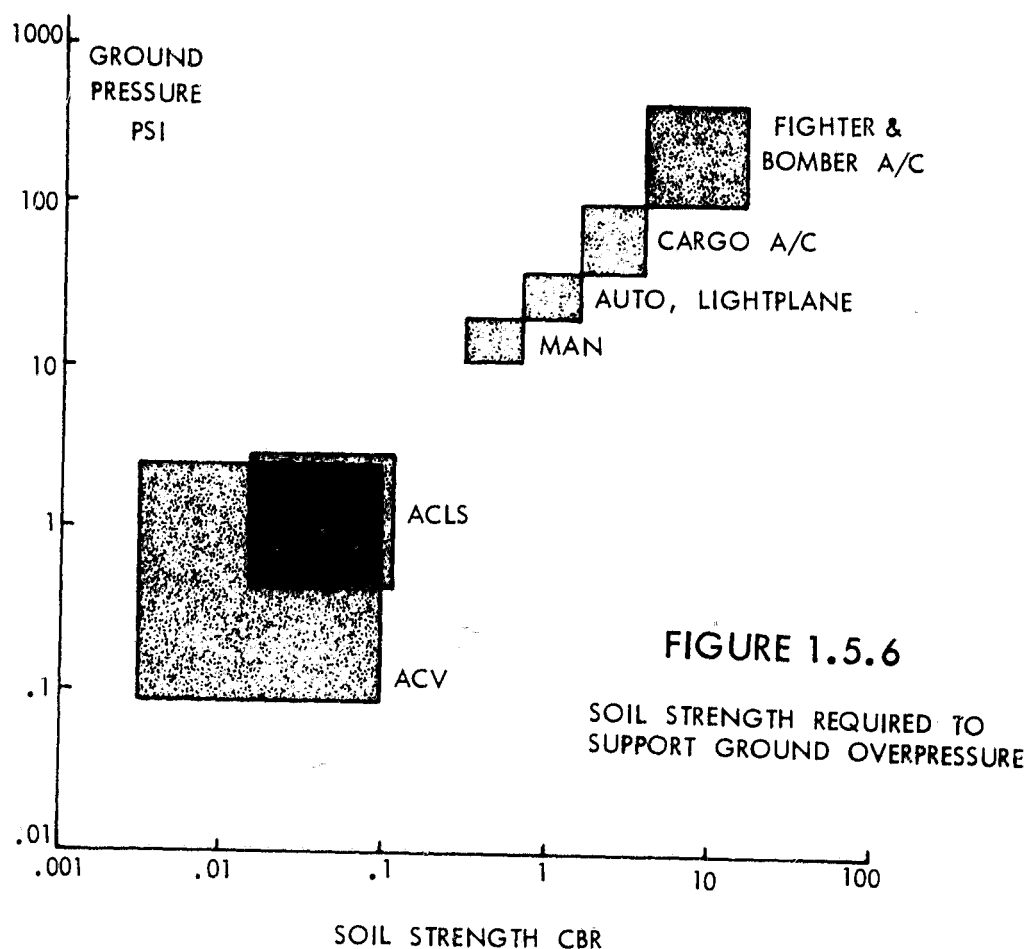
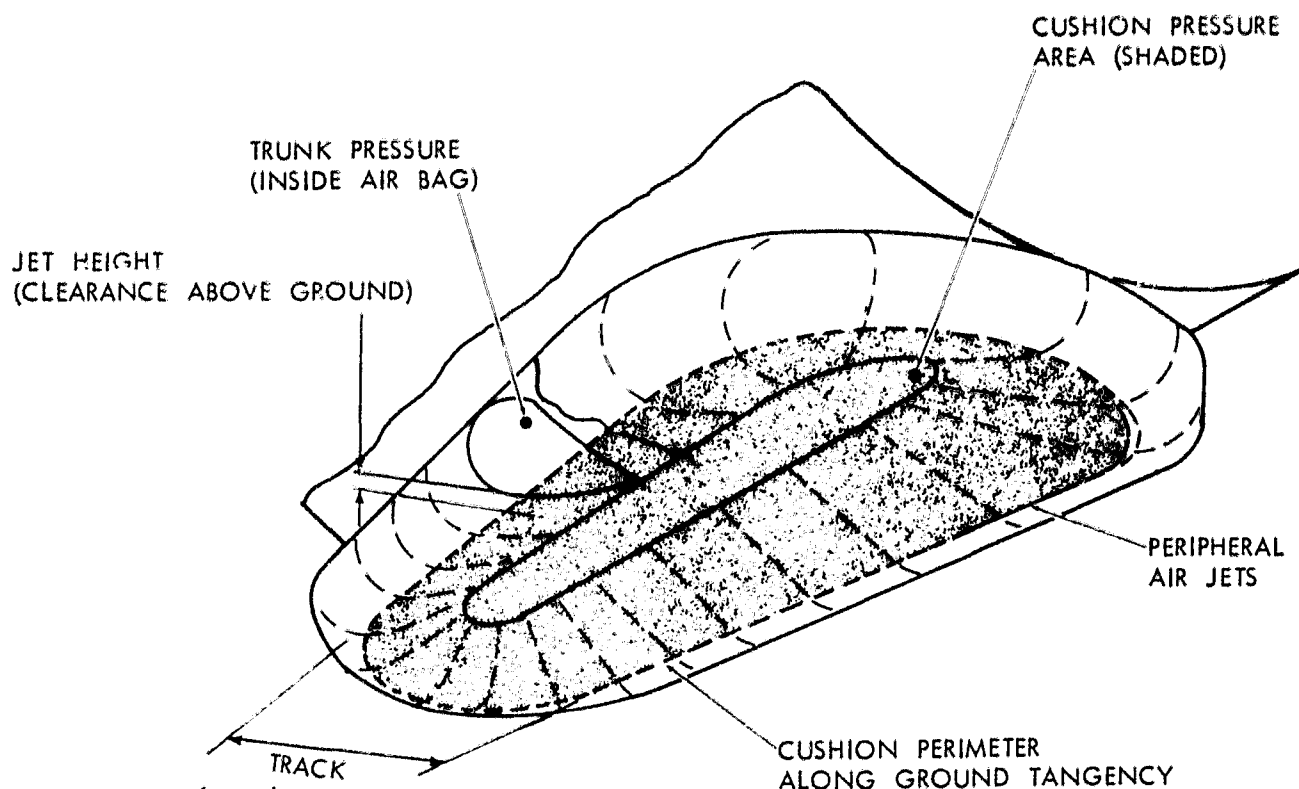


FIGURE 1.5.7
ACLS TYPICAL TRUNK PLENUM



Bearing Ratio (CBR). Auto and small general aviation aircraft tires exert pressures of 25 to 50 psi and are suitable for operation on relatively soft terrain. However, if mud, snow and water are to be encountered, the ACLS appears to provide the best solution. It lies in the area of emerging technology, having been subjected to considerable research and development during the last five years, including flight tests with an LA-4 airplane.

The system is designed to provide the ultimate in flotation, besides fulfilling the functions of vertical energy absorption, retraction, bracking and ground handling. Its basic elements comprise a low pressure, high volume air supply and flexible trunk plenum with peripheral jet exits. A typical trunk schematic is shown in Figure 1.5.7. The installed weight is generally less than that of a comparable wheel gear, but there is a power requirement as well. The latter, however, is generally about equal to that required to overcome ground friction, during takeoff, with a wheel gear. Although a pure ACLS is possible, it is recommended that an auxiliary wheel gear be added, designed for ground handling loads only. This addition will permit precise steering and mobility of the aircraft without using its own power.

Retractable tricycle wheel gear has been applied to the baseline aircraft derived in this study. In Category I, however, the ACLS has been applied to the recommended configuration as a means of increasing its utility. The ACLS would be highly suitable also, for "bush" operation, where a wide variety of terrain, including water, snow and ice, is encountered.

1.5.6 Functional Subsystems

Aircraft subsystems which benefit by the emergence of new technology include environmental, fuel, flight control and auxiliary power. Environmental subsystems include cabin pressurization and ice prevention. The advent of the turbocharger for piston engines and the use of compressor bleed air from turbo engines provide pressurized air sources, which need only be cooled to a comfortable temperature level. For anti-icing or de-icing the aerodynamic surfaces, heating or contour changing (with flexible, pressurized "boots") techniques can be used. The two methods can be combined by circulating hot, compressed air through a drooped leading edge formed by inflating a flexible boot.

Fuel system technology is being directed toward fire prevention and reliability. The safety aspects are discussed in Section 1.5.8. Flight control systems are moving in the direction of automation, with autopilots used in the higher-priced business aircraft. Fluidics and "fly-by-wire" systems are under development for military and commercial transports, but are not expected to be adopted by general aviation in the next fifteen years. Design of the control system should stress simplicity, ease of operation and human factors in an effort to promote reliability and safety.

1.5.7 Utility and Convenience Features

It stands to reason that the market for general aviation aircraft will increase beyond its normal growth rate if additional utility and convenience features can be provided without sacrifice of performance and without substantial increase in price. One example is the small boat market, which underwent an amazing growth after trailering was introduced. Small aircraft, exemplified by Category I, can be equipped with easily foldable wings for home storage and designed to be towed behind a car on the road. Going one step further, automotive capability can be added to make them independent of extra vehicle support. These capabilities have been subjected to sensitivity analyses in this study, with the result that the towable version appears to be a favorable configuration.

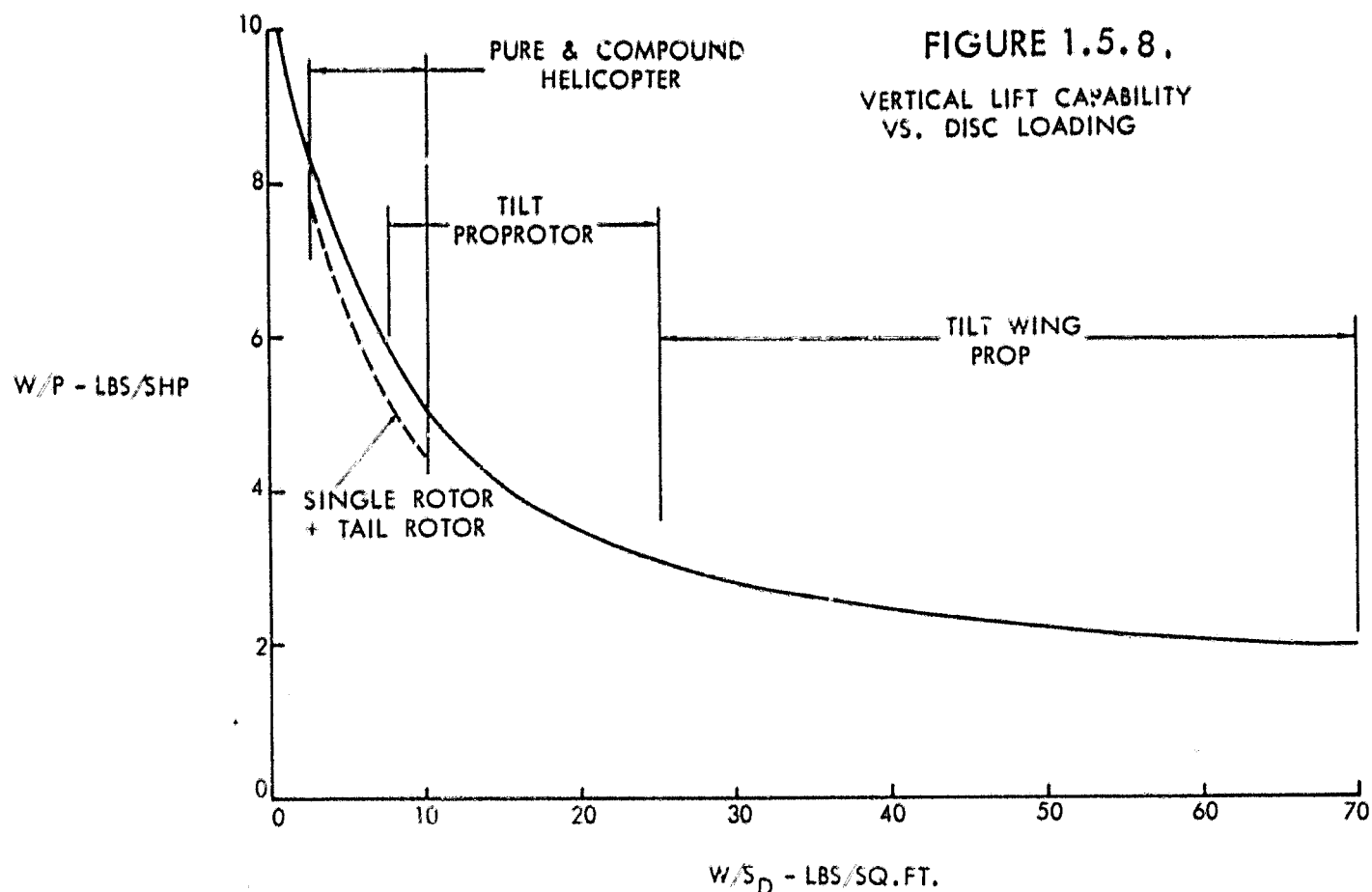
Emerging technology on the air cushion landing system can be applied to impart all-terrain operational capability to general aviation aircraft. This feature can be included without compromise to performance or cost. The recommended configuration for Category I, shown in Figure 1.9.1, includes both of the previously described features.

1.5.8 Safety Considerations

Safety is a fundamental, ever-present requirement in aircraft design and operation. FAA regulations establish a minimum level of airworthiness to which most manufacturers adhere. Technology has and will continue to offer means of increasing various aspects of safety without serious compromise of performance and cost. It is basic to safe design that one of two situations exist: a failure cannot occur; or, if a failure can occur, there is a way out.

General aviation accident statistics show pilot error to be the prime cause of all accidents, amounting to about 77%. Other factors causing accidents are adverse weather and terrain, and engine, airframe, or systems failure. The individual occurrence rate of these accidents is less than 7 percent of the total. However, many accidents charged to pilot error are induced by deficiencies in design of the aircraft, with particular relation to human factors. Airframe and subsystems safety can be enhanced by close attention to the engine installation, the fuel system and the control system, and by the design of damage tolerant structure, following the example of military and transport aircraft practice. In cases where damage is unavoidable, present technology offers many possibilities of avoiding crashes, and where crashes are inevitable, of minimizing the chances of severe injury and loss of life.

At least one aircraft, a helicopter, has been designed to sustain impacts up to 30 ft/sec, with peak accelerations up to 15 g in the cockpit, without serious injury to the occupants. The correct technique is to provide the maximum degree of structural deformation after impact, rather than to design the structure to sustain abnormally high loads. The use of an inflatable trunk, air cushion landing gear, is a step in this direction.



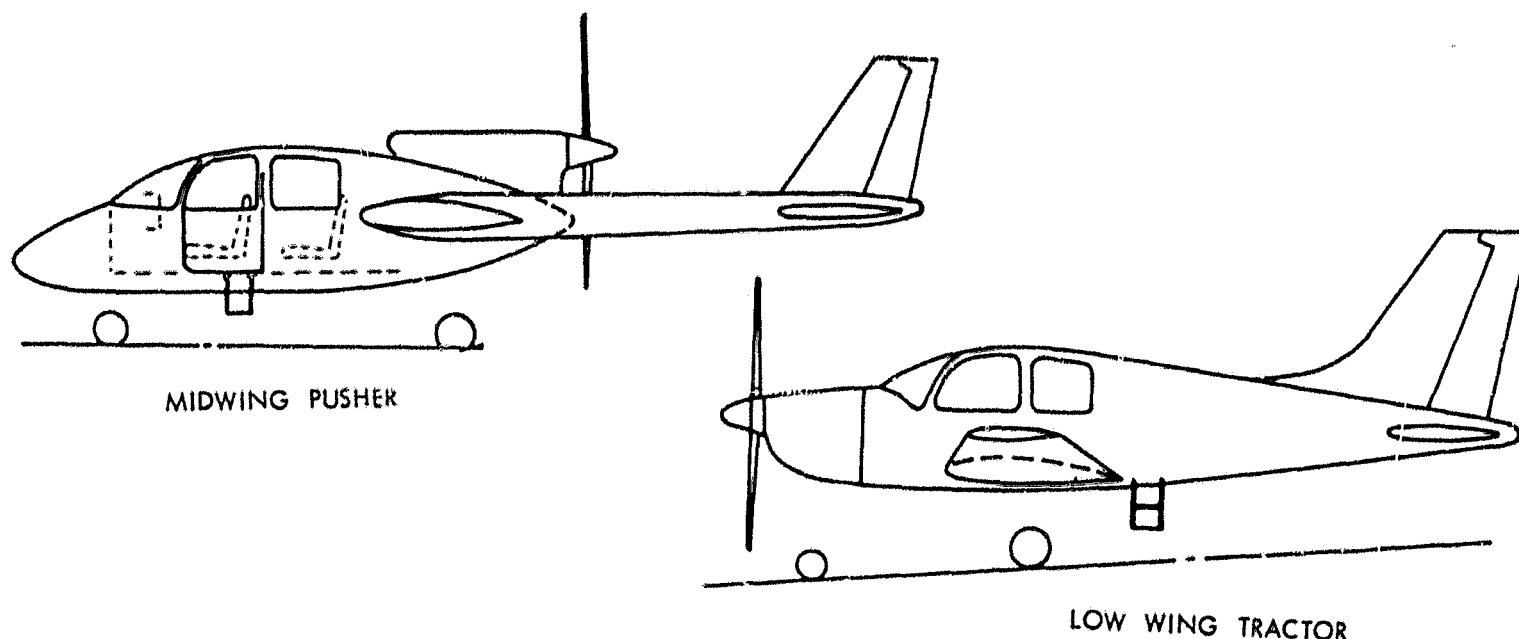
Safety from abnormal environmental conditions is an important aspect of the problem, with avoidance of storms a paramount consideration. This calls for accurate forecasting and effective data transmittal systems. While airborne weather radar sets are available, they are presently priced beyond the means of most small aircraft owners. Ice prevention and IFR equipment, however, can be made available at reasonable cost in the future.

1.5.9 VTOL Technology

VTOL aircraft, in the present and emerging state-of-the-art, fall into four main categories: Fixed rotor, tilt rotor, retractable rotor and fixed wing. The first three fall into the low disc loading classification, while the fourth, exemplified by jet- and fan-lift systems, has inherently high disc loading. Since it is necessary to have low disc loading in order to meet the low noise level constraint of this study, fixed wing concepts have not been considered. Low disc loading is desirable not only from the noise standpoint, but also because of ground erosion considerations. While the minimum cruise speed constraint, in Category IV, of 150 knots can be met with a pure helicopter design, it was considered expedient to look at configurations with a higher speed potential. Either the tilt wing or the tilting rotor can, at least, double the minimum required cruise speed. "Compounding" the helicopter can increase its speed to 200 knots or more. The technology relating to these approaches will be examined in the following subsections. A true VTOL aircraft must be capable of sustained hovering flight, and this requirement excludes the autogyro which is basically a STOL vehicle and was analyzed as such in the sensitivity portion of this study.

Figure 1.5.8 shows a plot of power loading versus disc loading for representative VTOL configurations. The term "power loading" may be considered the ratio of vertical lift obtained per unit of engine power required, hence a measure of vertical lifting efficiency. Although the tilt proprotor concept (implying fixed wings) usually lies in a lower range of disc loading than that of the tilt wing-propeller concept, this need not necessarily be the case for general aviation consideration. The investigators of this study chose the tilt wing configuration as an alternate to the helicopter, due to more familiarity with the concept.

FIGURE 1.6.1 CATEGORY I CANDIDATES
(4 PLACE, 1000' FIELD)



Speed constraints limit the pure helicopter to a practical maximum cruise level of 150-175 knots; the compound helicopter to 200 knots and the tilt rotor concepts to 400 knots. In the pure helicopter, the constraint is imposed by a combination of high Mach number of the advancing blade and stall of the retreating blade. Compound helicopters gain by unloading part of their lift on to fixed wings, while the tilt rotor designs do this entirely.

The principal element of any VTOL concept is the rotor. The single rotor concept, with an anti-torque tail rotor, has been more widely adopted than any other and is more efficient than the tandem concept over the usual speed range. The degree of rigidity designed into the rotor has an important effect on stability and control characteristics in the high speed range, with the "rigid" and semi-rigid types favored over the articulated arrangement.

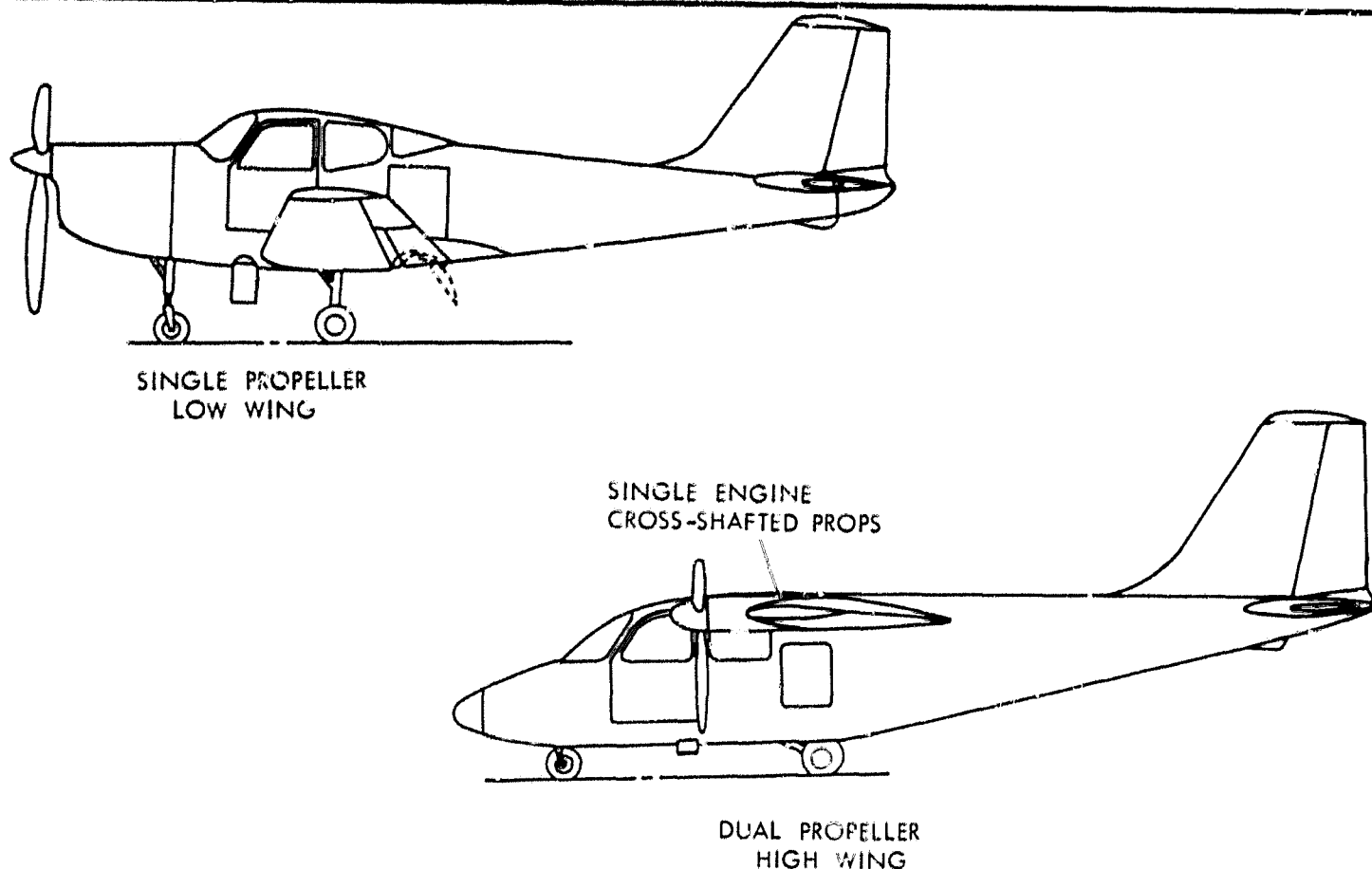
While the technology of the helicopter is well established, that of the tilt rotor concepts must be considered as emerging, and several problem areas are present. Eventually, solutions will be found with continued research and development applied to military VTOL requirements, which can have later application to general aviation.

1.6 Selection of Baseline Designs

The first step in the selection of competitive baseline configurations for the parametric analysis is that of choosing the candidates. The choice for each category was not made arbitrarily. A number of practical configurations for each category were selected for intuitive consideration. A point system was created, assigning weighted maximum point values to such criteria as cost, safety, flying qualities, performance, comfort, reliability and growth potential. Members of the study team and technical advisory personnel were asked to assign points for each criterion to all of the configurations nominated in each category. This resulted in the selection of two per category for the parametric analysis.

The Category I candidates, shown in Figure 1.6.1, include a single engine, low-wing, tractor propeller design and a single engine, mid-wing, tail boom pusher propeller configuration. The former has the advantages of shorter length, lighter weight and lower drag, while the latter combines better visibility, lower cabin noise level and easier cabin access. However, other considerations are involved, and only the results of parametric analysis can lead to a selection.

FIGURE 1.6.2 CATEGORY II CANDIDATES
(4-PLACE, 500' FIELD)

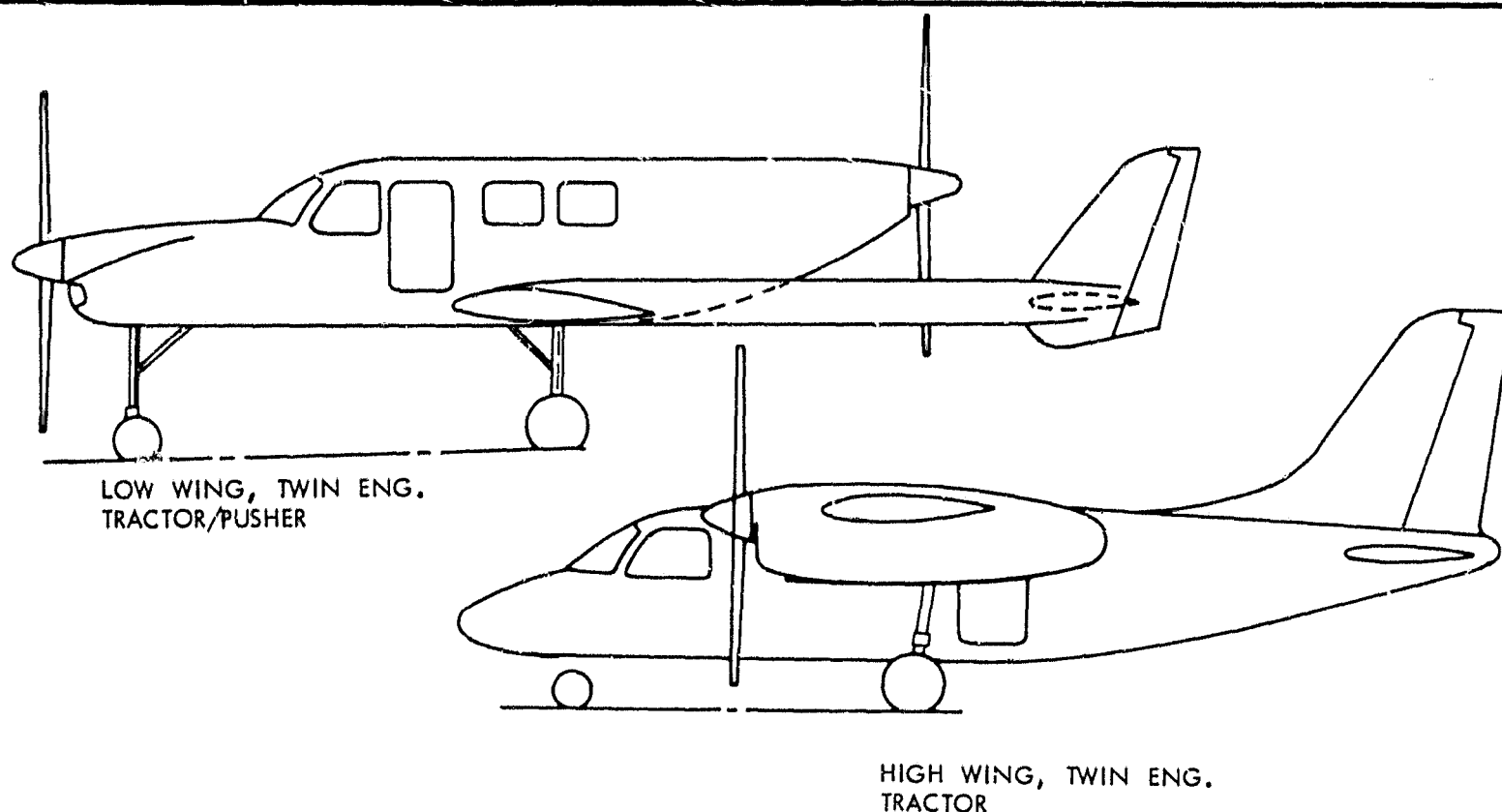


The Category II candidates are illustrated in Figure 1.6.2, both of which are single engine designs. One is configured with a low wing and a single tractor propeller and the other with a high wing and two outboard tractor propellers driven by a cross shaft. However, in the final analysis, a single pusher propeller design was chosen. The advantage of the tractor propeller in providing lift augmentation by slipstream deflection cannot be used to establish minimum flight speed, since engine failure during takeoff and landing operations would create an abrupt stall.

In Category III, both candidates shown in Figure 1.6.3 are twin engine aircraft. One is a conventional high wing configuration with tractor propellers, while the other is a tractor-pusher arrangement with both engines on the center line. The extremely large propeller diameters required to meet the specified noise level favor the high wing, tractor configuration from the standpoint of cabin access and appearance. However, the propellers have to be located so far outboard that an interconnecting cross shaft is required for control with one engine inoperative.

In an effort to assess the effect of providing a higher cruise speed, a configuration using a single turbofan engine was added to Category III for the sensitivity analysis. The reasons against using twin turbofans are excessive cost and the established better reliability of the turbofan over the shaft engine propeller combination.

FIGURE 1.6.3 CATEGORY III PROPELLER CANDIDATES
(6 PLACES, 1500' FIELD)



With a minimum cruise speed requirement of only 150 knots, the helicopter is a prime candidate in Category IV. Since higher speed is a desirable characteristic, a tilt-wing-propeller configuration was selected as a competitor. Both are shown in Figure 1.6.4. The relatively high power requirements, especially for the tilt wing, led to the use of a turboshaft engine. The helicopter design is conventional and constrained as to disc loading and rotor solidity ratio by the requirement for low noise level. The tilt wing is similarly constrained, and its tilting motion is interconnected with flap travel to develop maximum lift and avoid stall during the transition.

FIGURE 1.6.4 CATEGORY IV CANDIDATES
(4-PLACE, VTOL)

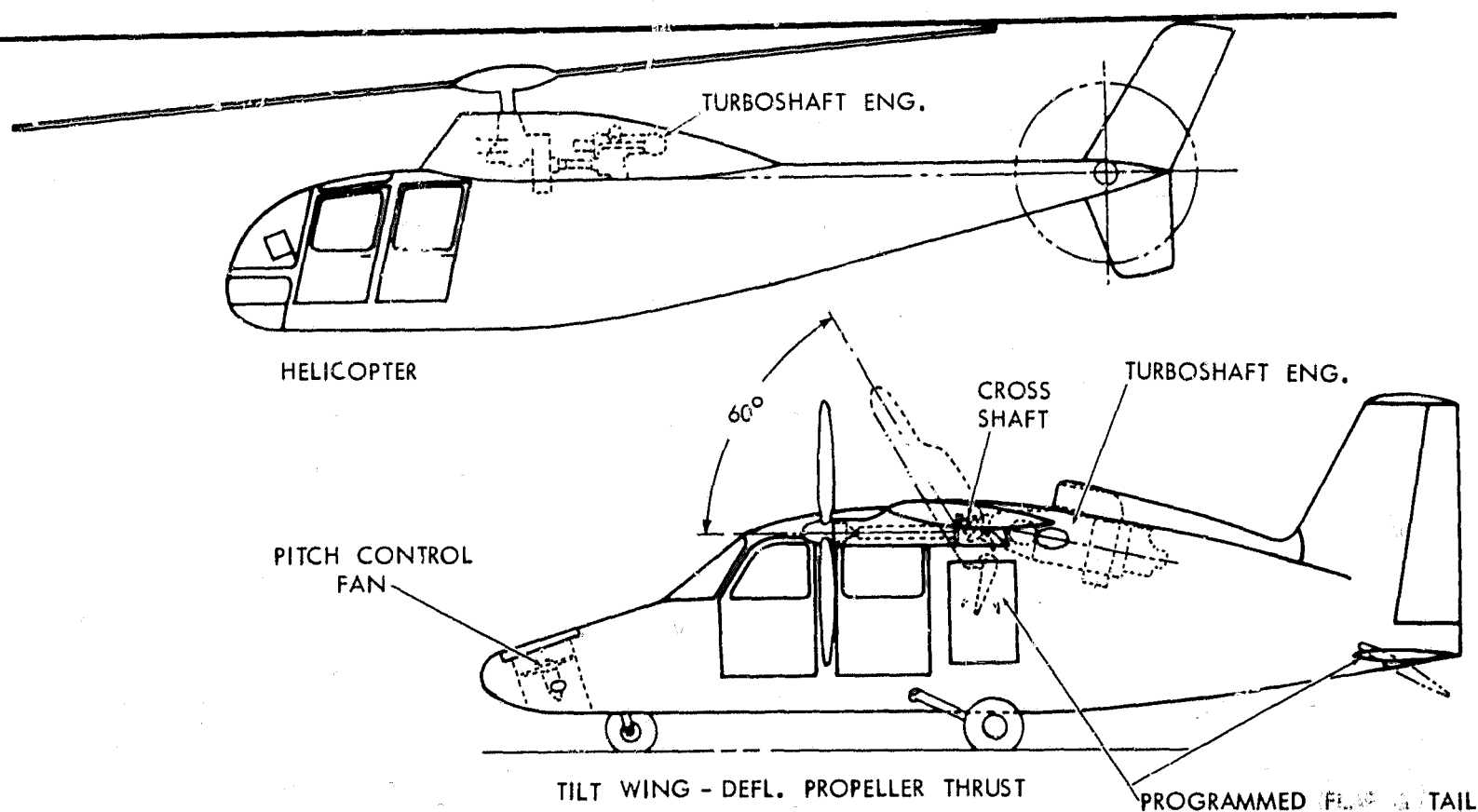
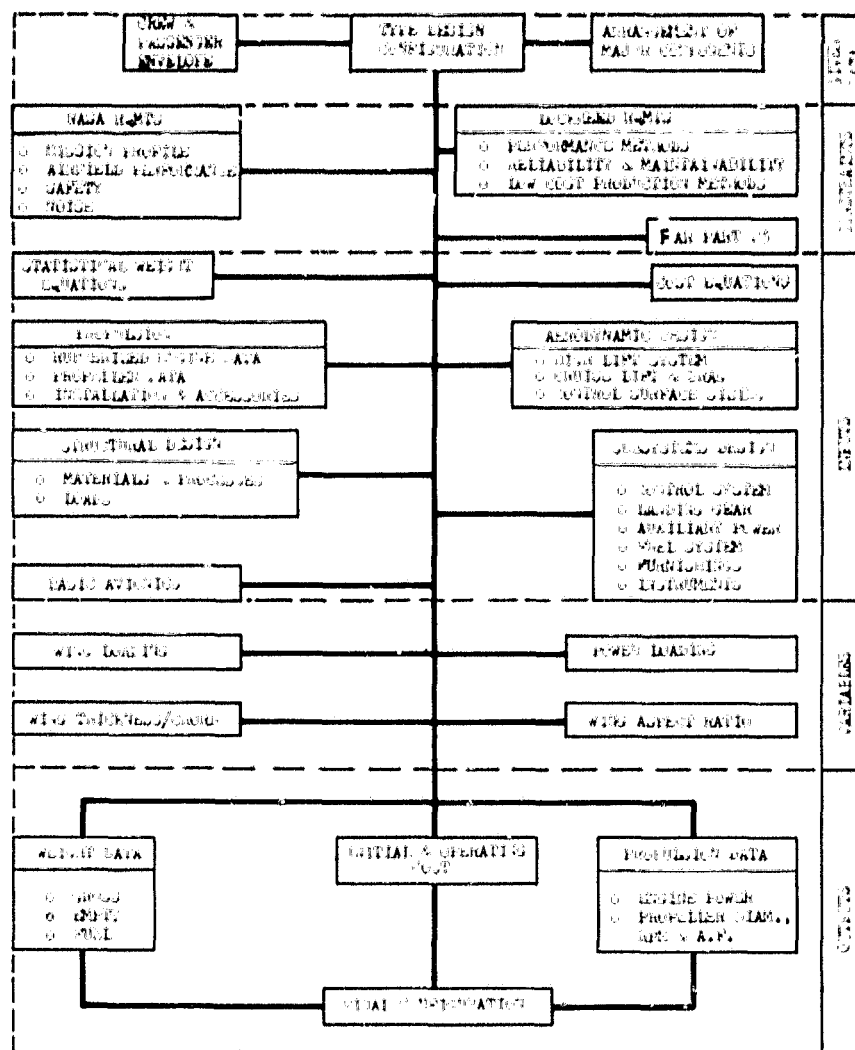


FIGURE 1.7.1 PARAMETRIC FLOW DIAGRAM

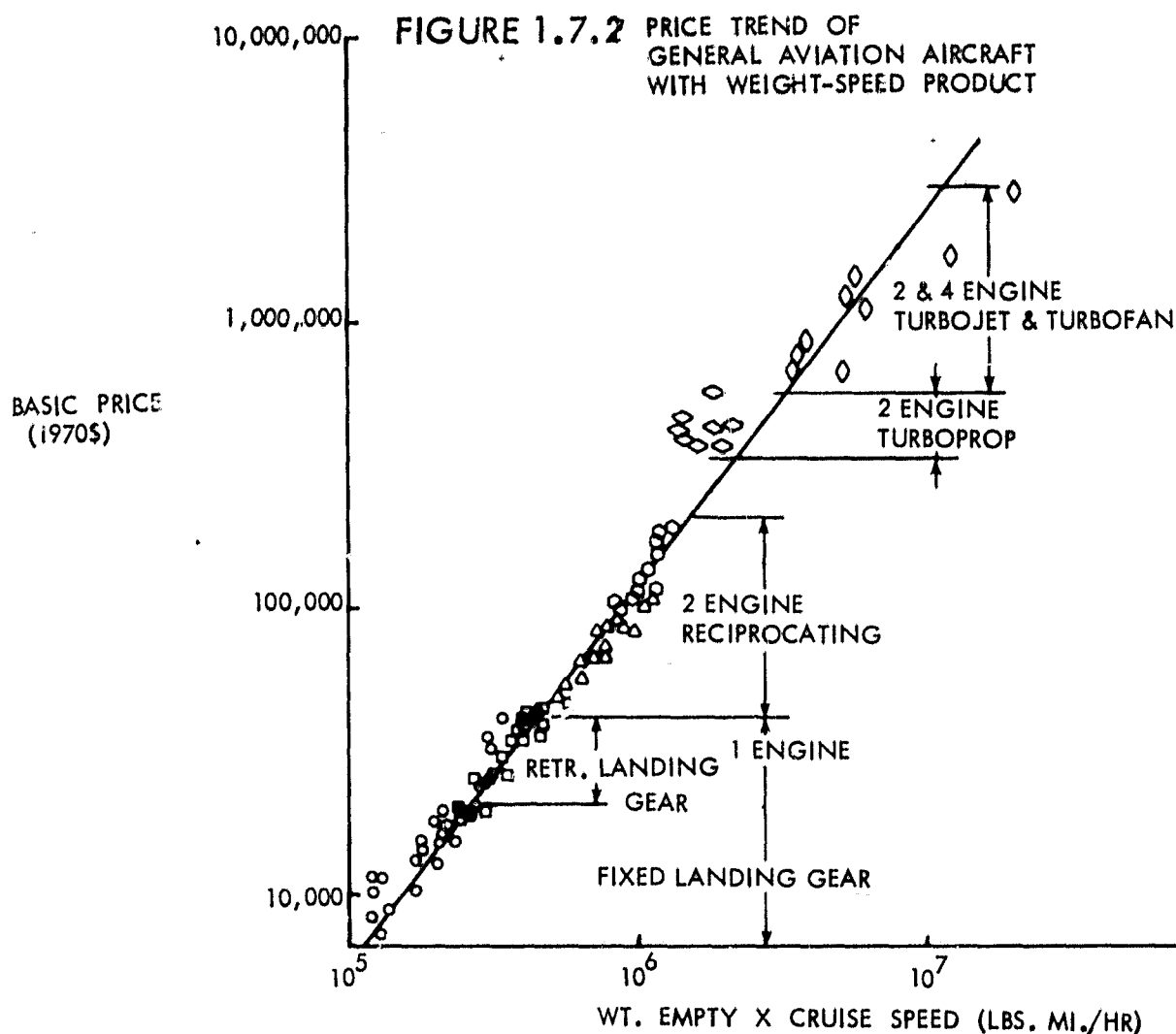


1.7 Parametric Analysis

1.7.1 Methodology

The parametric analysis procedure used in this study is applicable to optimization of the present technology baseline designs, covered in this section, and to the sensitivity analyses, covered in Section 1.8. The computerized analysis has the capability of estimating performance, costs, and weights.

Figure 1.7.1 shows a flow diagram of the procedure. Initial inputs to the analysis comprise an assumed gross weight, wing aspect ratio, cruise speed and altitude, cruise drag coefficient and cruise propeller efficiency. Cruise power is then determined, after which the range, specific fuel consumption and the weight subroutine are entered using an assumed gross weight. A complete weight analysis is then made from the weights subroutine on the basis of vehicle geometry, payload and fuel requirements, and gross weight is calculated. The calculated gross weight is checked against the assumed gross weight and an iteration process is performed until the difference is within a specified tolerance. The static propeller thrust-to-horsepower ratio (for the required noise level) and the ratio of takeoff power-to-cruise power are input to calculate takeoff distance. The output is compared to the required figure and additional iterations of gross weight and power are performed until stabilized outputs are determined. The readouts include: gross weight; weight empty and its subdivisions; fuel capacity; L/D; wing area; wing loading; rated T.O. power; takeoff distance; initial cost and operating cost.



Inputs to the program are based on present technology for the establishment of baseline configurations and advanced technology for the sensitivity analyses. These include propulsion and structural material, with others as appropriate to the desired assessment.

Statistical formulas were derived for the determination of structural, subsystem and equipment weights, while that of the engine is based on rate power and technology level. The latter factor is also applied to the structural weight groups.

The collection and correlation of cost data was a major undertaking of this study. Costs were subdivided into initial and operating cost. Statistical data were compiled from literature, contributions from general aviation aircraft manufacturers, and from NASA. Engine and propeller cost data were obtained from the leading manufacturers. Cost trend curves for complete aircraft (excluding avionics) were developed as a function of the Weight Empty X Cruise Speed product, as shown in Figure 1.7.2. A breakdown process from the list price was developed so that the effects of each component part - airframe material and labor; engine, propeller and equipment; overhead, profit and dealer's commission - can be separately assessed. The cost per pound of helicopter airframe was found to be considerably higher than airplane hardware. Projections were made into the 1985 time period, assuming that fiber composite materials will be used. This included estimates of material cost per pound and a study of applicable manufacturing methods for minimum man-hours per pound. Learning curve slopes were developed for the assessment of high production quantities - up to 100,000 units per year. Case histories were studied in an effort to check development costs, which are usually amortized in production costs. A figure of \$1000 per pound of gross weight appears to represent an average for general aviation aircraft. The initial cost model was used to check the cost of actual aircraft and was found to be accurate within 10%.

FIGURE 1.7.3 OPERATING COST FACTORS SUMMARY

ELEMENT	CATEGORY			
	I	II	III	IV
<u>VARIABLE COST (HOURLY)</u>				
FUEL & OIL	AVG. FLOW, COST/GAL.			
INSPECTION & MAINT.	EMPTY WEIGHT, TOTAL POWER			
RESERVE FOR OVERHAUL	TOTAL ENGINE POWER			
PARKING, LANDING, SPARES	\$.55	\$.90	\$ 1.70	\$ 1.70
<u>FIXED COST (ANNUAL)</u>				
DEPRECIATION	20 YEAR LINEAR			
INSURANCE				
HULL	4%	3%	2%	12%
LIABILITY	\$ 200	\$ 300	\$ 450	\$ 800
FAA USE TAX	\$ 25 + GW CHARGE			
STORAGE	\$ 300	\$ 600	\$ 900	\$ 600
PILOT	-	-	\$ 15,000	\$ 15,000
MISCELLANEOUS	\$ 100	\$ 150	\$ 200	\$ 200

An operating cost model was developed using various sources of information, with particular reference to a DOT report (Reference 1.6). Operating cost factors are listed in Figure 1.7.3 showing differences assumed in each of the four categories. Categories III and IV aircraft were assumed to be flown by professional pilots. Program readouts included cost per hour, cost per mile and cost per seat-mile for yearly utilization figures of 100, 300 and 500 hours. The effect of utilization on aircraft-mile cost for all Categories are shown in Figure 1.7.4, which tends to emphasize the need of high utilization for economic operation.

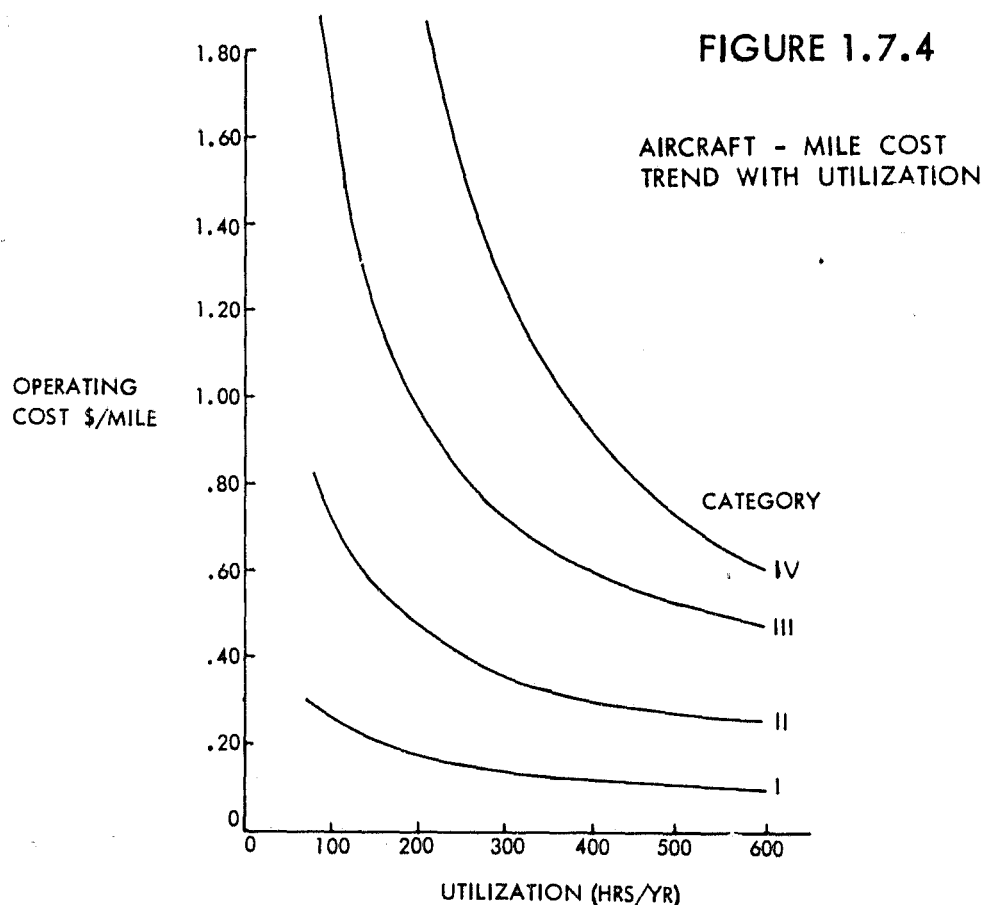


FIGURE 1.7.5 CATEGORY I PARAMETRIC
ANALYSIS RESULTS

CONFIGURATION	TRACTOR	PUSHER
GROSS WT. (LBS.)	2,847	2,810
TYPE OF ENGINE	RECIP	RECIP
T.O. BHP	175	174
CRUISE SPEED (KTS)	145	145
CRUISE POWER (PCT. NORM.)	75	75
PROP. THRUST (LBS/HP)	6.0	6.0
PROP. DIAM. (FT)	7.91	7.91
WING LOADING (LBS./SQ.FT.)	11.84	12.16
INITIAL COST (\$)	30,373	29,669
OPERATING COST (\$/MILE) 300 HRS/YEAR	0.158	0.156

1.7.2 Results and Baseline Configuration

The first step in the parametric analysis was the establishment of baseline designs in each of the four categories. The program analyzed the competitive configurations in each category. The airplane selected from each configuration study was selected on the basis of the lowest gross weight and direct operating cost. These were then compared and one was selected as a basic configuration for the sensitivity studies.

Category I aircraft are equipped with present technology reciprocating engines, which propel them in cruise flight at 75% of normal rated power. A comparison of the tractor and pusher propeller candidates, shown in Figure 1.7.5, reveals that they are very close in weight, power and cost. A cruising speed of 145 knots, with retractable landing gear, was chosen as the highest obtainable without an appreciable increase in operating cost. A check was made in this category to assess the effect of using conventional propellers with a much higher noise level. Surprisingly, use of a low noise level propeller produces an airplane which is lighter and less costly to buy and operate. This conclusion was found applicable to Category I only.

Figure 1.7.6 shows the mid-wing, pusher propeller configuration selected as the baseline design for Category I. Since it was only marginally better than tractor, it was selected more for qualitative reasons. These include: superior vision, low interior noise level, easy access to the cabin and safety from whirling propeller contact on the ground.

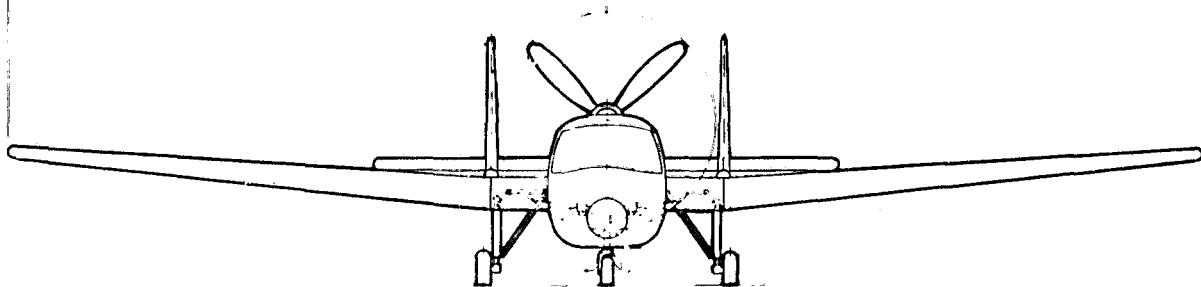
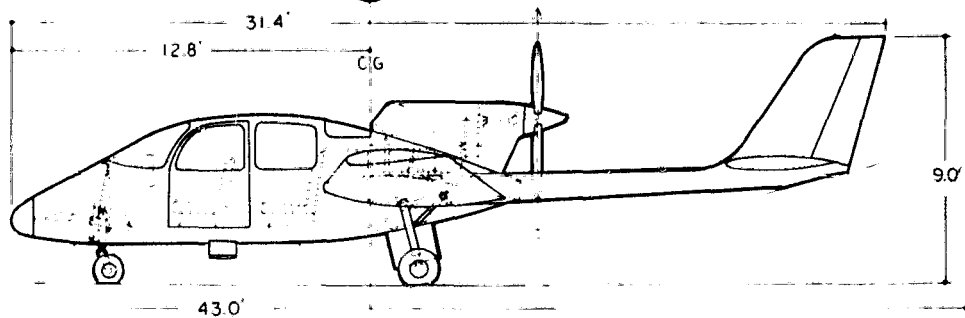
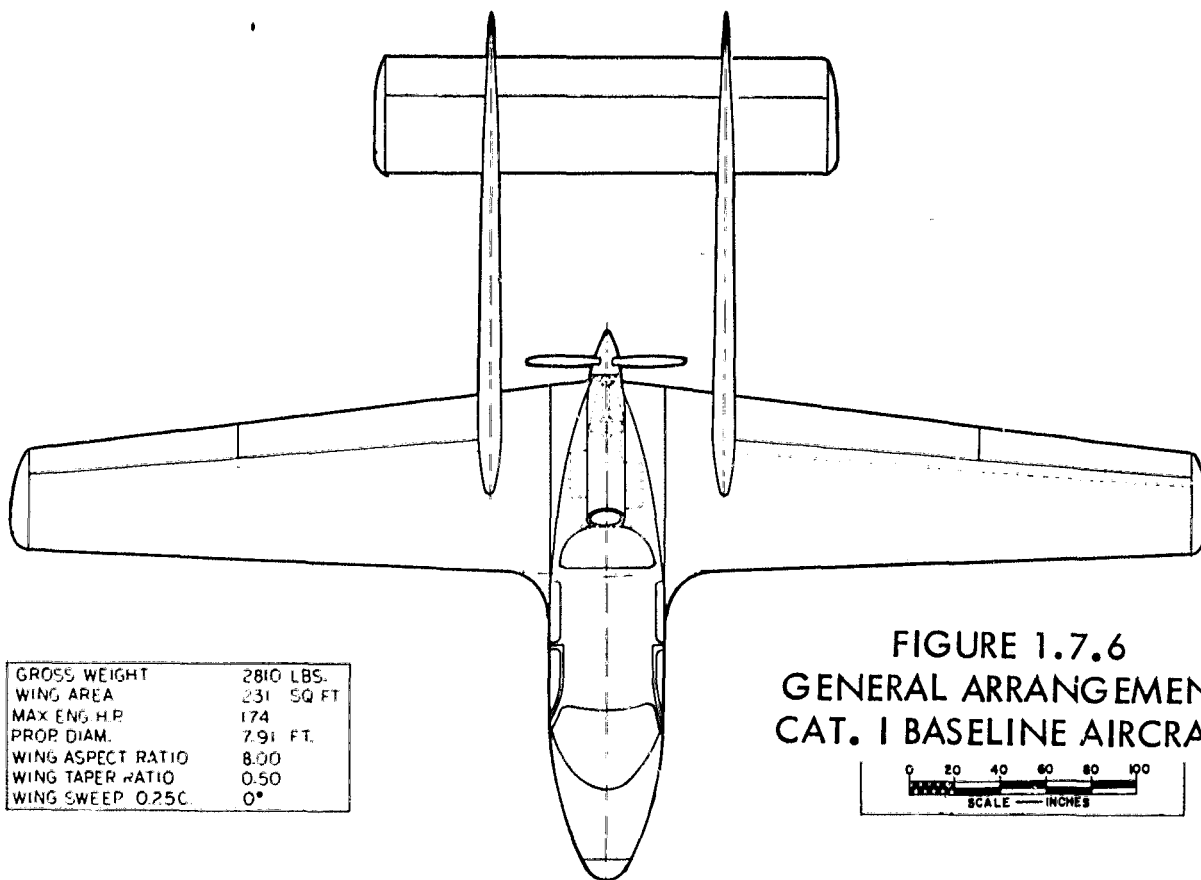


FIGURE 1.7.7 CATEGORY II PARAMETRIC
ANALYSIS RESULTS

CONFIGURATION	SINGLE PROP.	TWIN PROP.
GROSS WT. (LBS)	4,600	6,450
TYPE OF ENGINE	TURBCPROP	TURBOPROP
T.O. BHP	545	600
CRUISE SPEED (KTS)	200	200
CRUISE POWER (PCT. NORM.)	80	90
PROP. THRUST (LBS/HP)	5.0	6.0
PROP. DIAM. (FT.)	12.0	11.8
WING LOADING (LBS/SQ. FT.)	12.0	11.4
INITIAL COST (\$)	131,500	215,000
OPERATING COST (\$/MILE) 300 HRS/YEAR	0.335	0.475

Category II aircraft are equipped with turboprop engines, which were found superior to the reciprocating type on all counts. In this instance, cruise power is 90% of normal rated. Figure 1.7.7 shows a comparison between the single and twin propeller versions, which points to the former as the better approach. Having selected a single propeller configuration, it was decided to retain the pusher installation, as in Category I, for the same reasons. While the tractor propeller has the apparent advantage of slipstream deflection by the wing to augment lift, failure of the engine at a critical moment during takeoff or landing would lead to an abrupt stall. This dictates that minimum speed be based on power-off lift, negating the lift augmentation advantage of the tractor propeller.

Figure 1.7.8 shows the general arrangement of the Category II baseline airplane. Since it is similar to the Category I airplane in design approach, it reflects the penalties paid for reducing the field length from 1000 ft. to 500 ft. These include a 64% higher weight, a 66% larger wing and over 200% more engine power. Initial cost is increased by a factor of about 5.

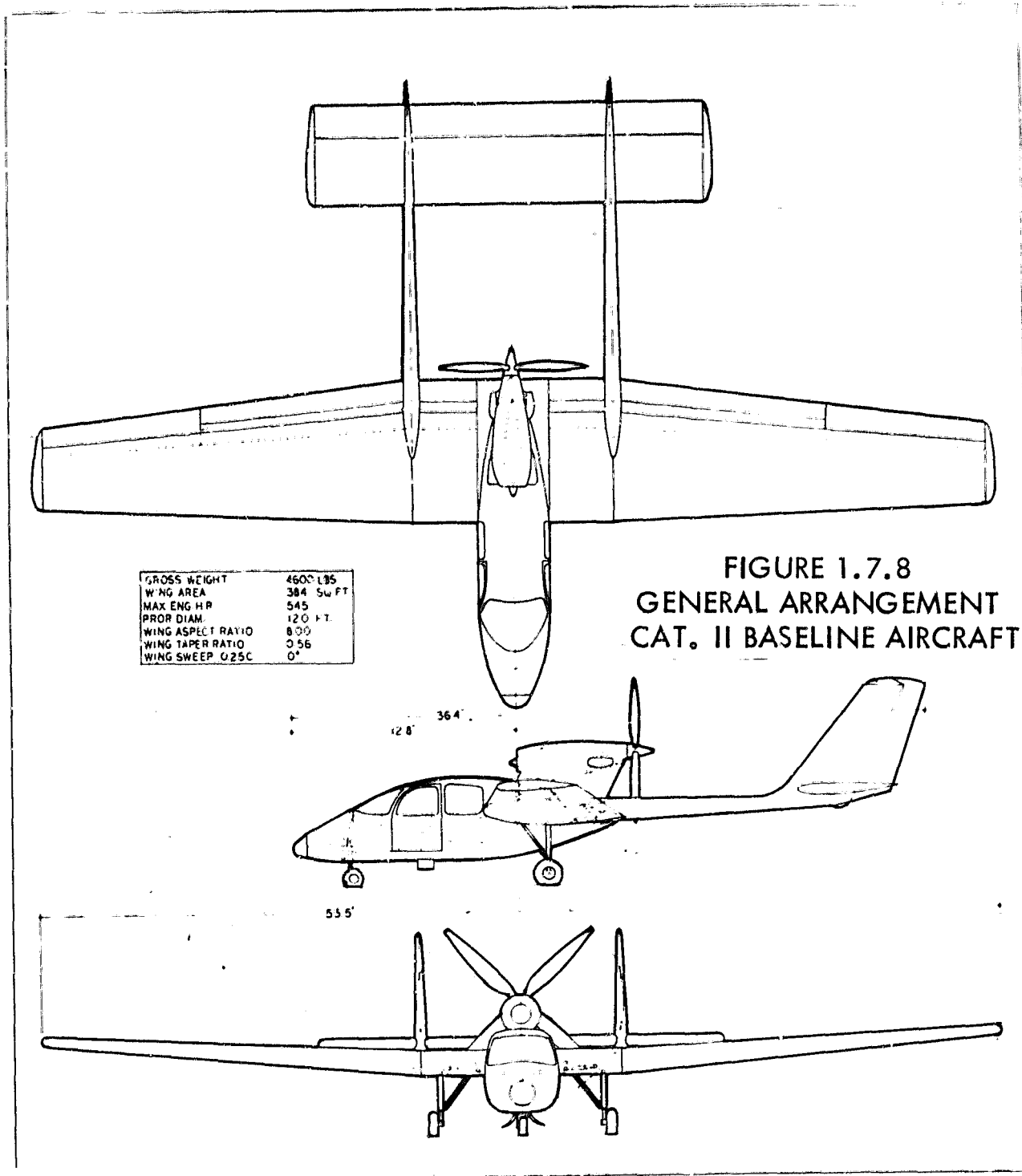


FIGURE 1.7.9 CATEGORY III PARAMETRIC
ANALYSIS RESULTS

CONFIGURATION	TRACTOR-PUSHER	TWIN TRACTOR
GROSS WT. (LBS.)	11,283	9,778
TYPE OF ENGINE	TURBOPROP	TURBOPROP
T.O. BHP	557	532
CRUISE SPEED (KTS)	250	250
CRUISE POWER (PCT. NORM.)	90	90
PROP. THRUST (LBS/HP)	5.0	6.0
PROP. DIAM. (FT.)	18.2	17.7
WING LOADING (LBS/SQ. FT.)	29.4	40.9
INITIAL COST (\$)	426,181	356,000
OPERATING COST (\$/MILE) 300 HRS/YEAR	0.82	0.74

Category III aircraft are also powered by turbine engines, as a result of a comparison study with piston engines. The conventional twin engine approach with tractor propellers, was evaluated against the centerline twin engine installation having tractor and pusher propellers. The comparison is tabulated in Figure 1.7.9, where the advantages of the conventional arrangement are apparent. It has the same symmetrical thrust characteristics of the centerline engine model, since the propellers, because of their large size and consequent outboard location, must be cross-shafted. The general arrangement of the selected design is shown in Figure 1.7.10 which graphically portrays the large propeller diameter required to meet the low noise level constraint.

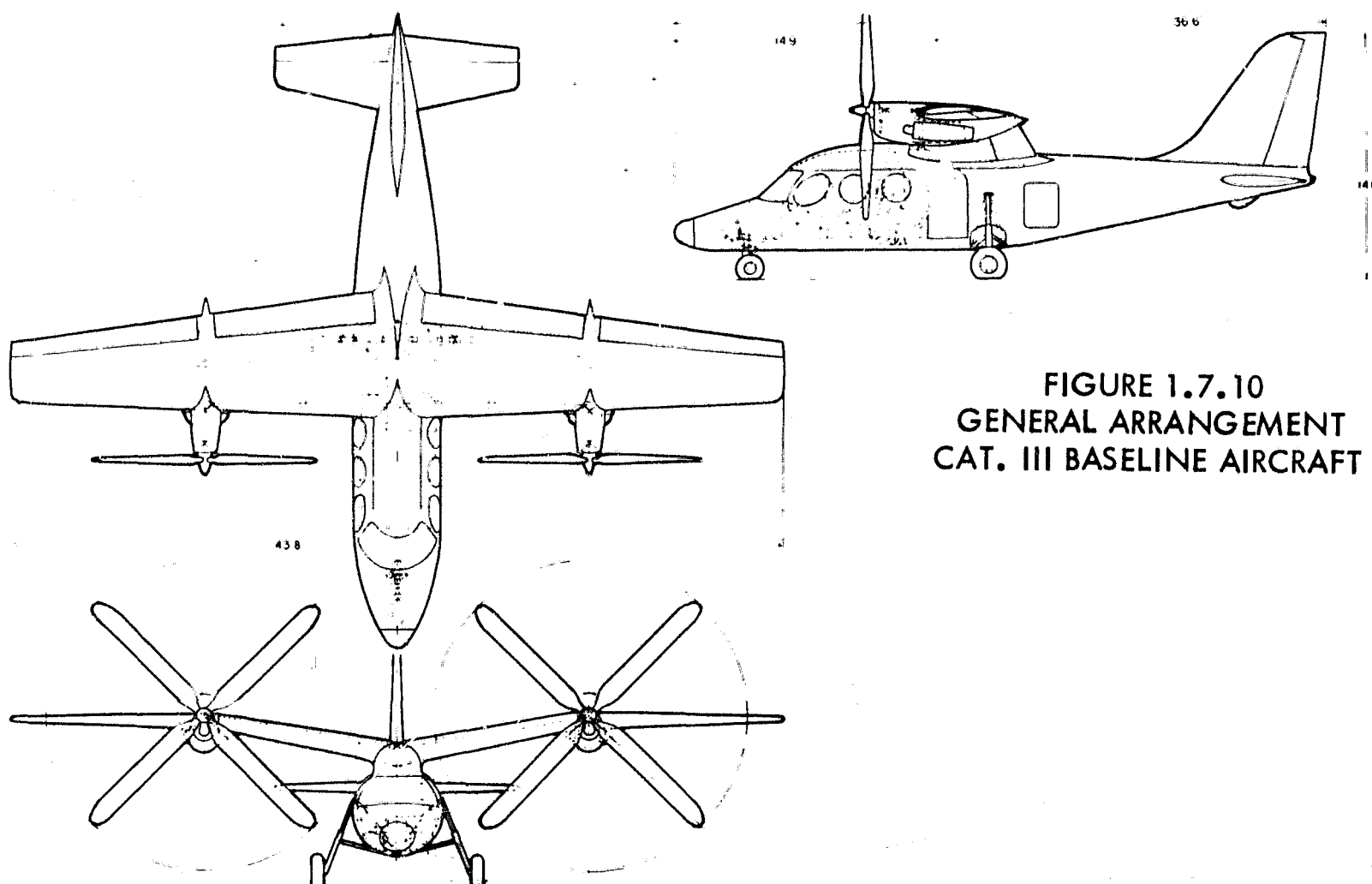


FIGURE 1.7.10
GENERAL ARRANGEMENT
CAT. III BASELINE AIRCRAFT

FIGURE 1.7.11
CATEGORY IV PARAMETRIC
ANALYSIS RESULTS

CONFIGURATION	TILT-WING- PROPELLER	HELICOPTER
CRUISE SPEED (KTS)	300	150
TYPE OF POWER PLANT	TURBOSHAFT	TURBOSHAFT
GROSS WEIGHT (LBS)	6918	5646
PROPELLER OR ROTOR DIAMETER (FT)	(2) 19.9	(1) 47.2
MAX. RATED HORSEPOWER	1282	641
WING AREA (SQ. FT.)	133	-
WING SPAN (FT.)	25.0	-
DISC LOADING (PROP. OR ROTOR) (LBS/FT. ²)	11.24	3.40
WEIGHT EMPTY (LBS.)	4756	3502
FUEL WEIGHT (LBS)	1262	1265
INITIAL COST (\$)	376,000	270,406
OPERATING COST (\$/MILE) 300 HRS/YR	1.03	1.39

The Category IV aircraft comparison placed the tilt wing - propeller concept against the helicopter. Again, turbine engines are used, reflecting contemporary VTOL aircraft practice. Figure 1.7.11 shows how the two approaches compare, reflecting the differences in disc loading. The tilt wing has twice the cruise speed, but also requires twice as much power. This effect escalates its price to 40% more than that of the helicopter, although its operating cost is about 25% lower. Since VTOL aircraft are operated, mainly, over shorter distances as compared with fixed wing aircraft, the speed advantage of the tilt wing is not considered to be worth its higher price. The helicopter was therefore selected, and its general arrangement is shown in Figure 1.7.12. Its comparatively large rotor diameter, with a high solidity ratio, reflects the low noise level and high cruising speed requirements.

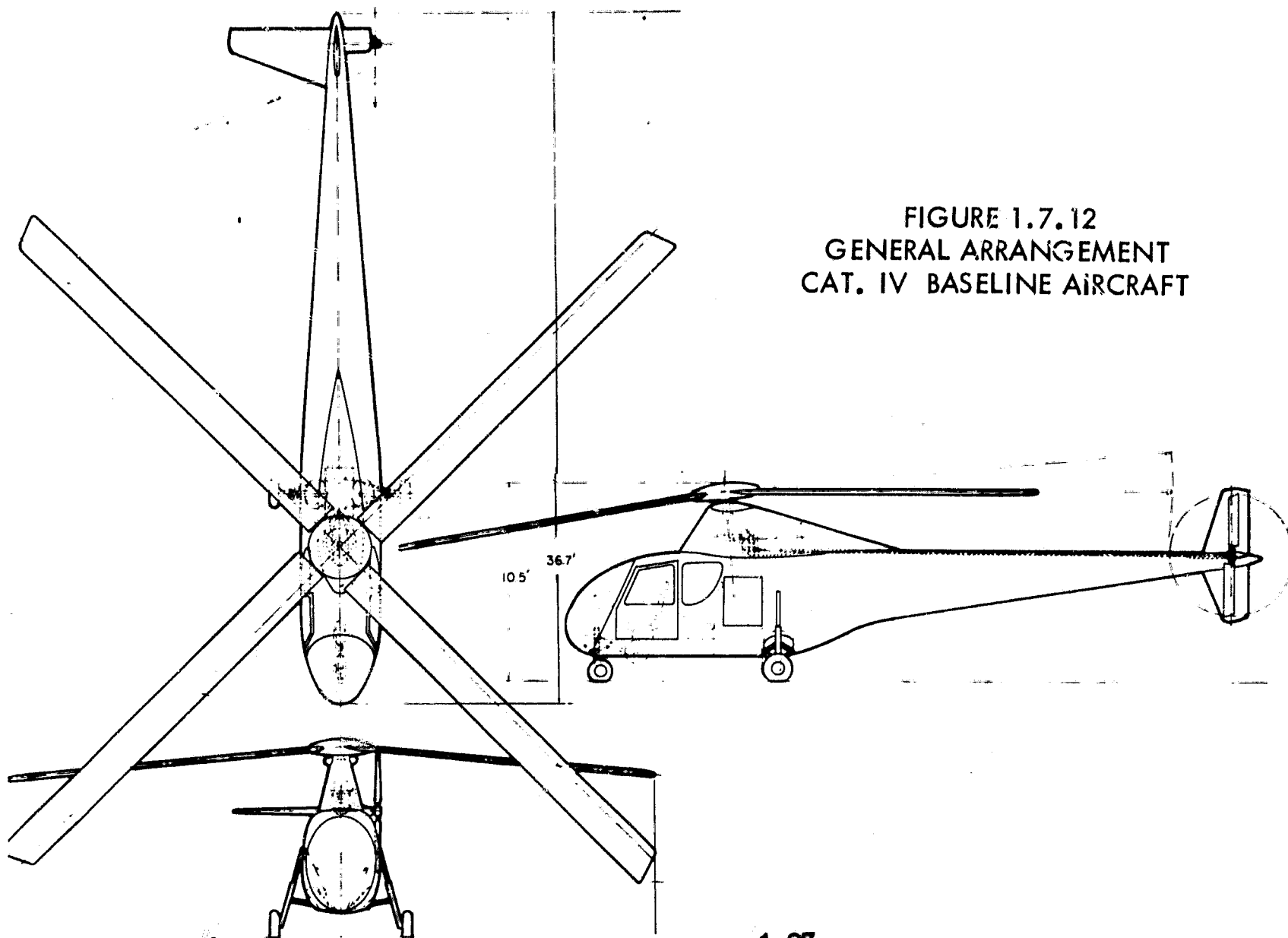
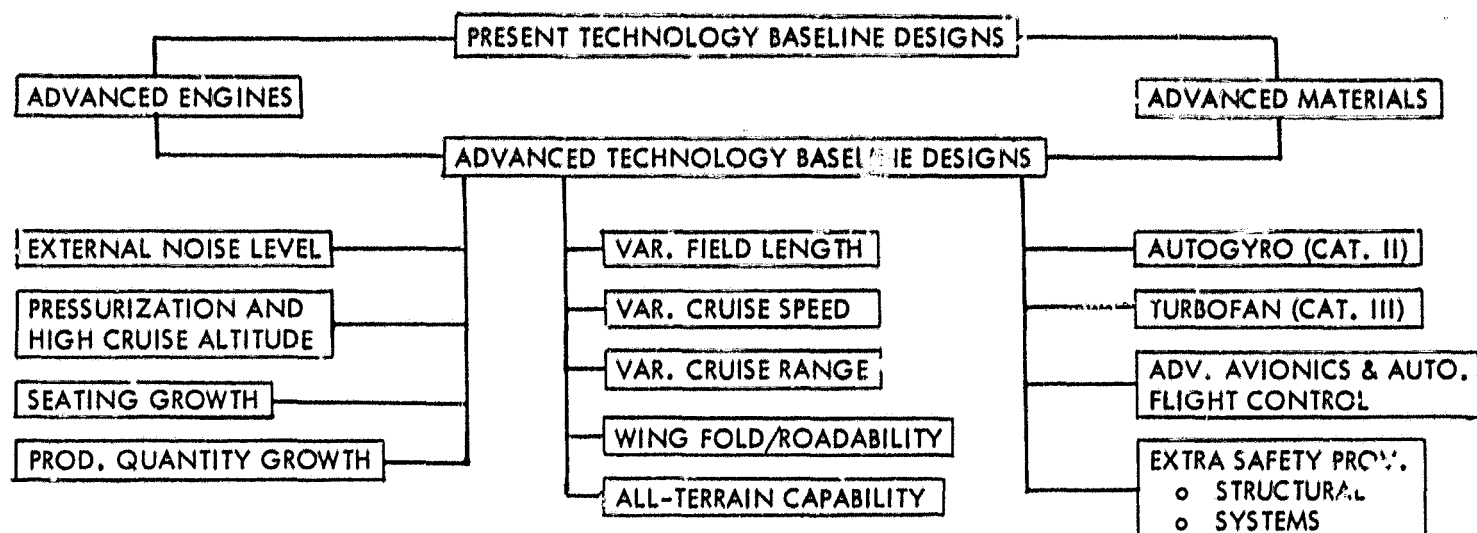


FIGURE 1.7.12
GENERAL ARRANGEMENT
CAT. IV BASELINE AIRCRAFT

FIGURE 1.8.1
SENSITIVITY ANALYSIS PROCEDURE



1.8 Sensitivity Analyses

1.8.1 General Procedure

Having established the present technology baseline designs and having examined the emerging technology, the next step consists of the series of sensitivity analyses outlined in the chart. The analyses follow the same computerized procedure used in the parametric analyses.

The purpose of this analysis is to assess the impact of advanced technology and other factors on the baseline designs reported in Section 1.7. Figure 1.8.1 illustrates the general procedure, which begins by assessing the impacts of advanced engine and advanced material technologies, separately and in combination. The latter establishes new baseline configurations, with which the remaining factors are assessed. Inputs and outputs of the computerized analysis are of the same type as described in Section 1.7.1.

1.8.2 Advanced Technology Baseline Designs

The advanced technology baseline designs were established by assessing the effect of advanced propulsion systems and the use of advanced structural materials. These effects were analyzed separately and in combination.

From the examination of applicable propulsion systems in Section 1.5.2, four types of engines were selected: reciprocating, turboprop, turbofan and rotating combustion (RC). The first three represent present state-of-the-art, while the fourth must be classified as emerging. The baseline designs are powered by either reciprocating or shaft turbine engines. The sensitivity analyses assess the RC engine installation as a power plant for each category of aircraft. The results expressed as percentage improvements over the baseline aircraft characteristics are listed in Figure 1.8.2.

FIGURE 1.8.2
EFFECT OF ADVANCED PROPULSION
(ROTATING COMBUSTION ENGINES)

CATEGORY	I	II	III	IV
BASELINE ENGINE	RECIP.	TURBOPROP	TURBOPROP	TURBOSHAF
PCT. IMPROVEMENT				
GROSS WEIGHT	4.5	6.1	4.9	20.3
MAX. H.P.	3.0	0.8	20.8	15.9
INITIAL COST	15.8	50.1	28.8	35.3
* 300 HRS/YR UTILIZATION				
OPERATING COST *	6.5	17.5	3.6	20.2

FIGURE 1.8.3
EFFECT OF ADVANCED MATERIALS
(FIBER COMPOSITES)

CATEGORY PCT. IMPROVEMENT	I	II	III	IV
GROSS WEIGHT	11.4	17.0	8.5	17.5
MAX. H.P.	8.3	12.5	1.4	13.9
INITIAL COST	17.0	18.5	13.2	13.1
OPERATING COST *	11.9	15.5	6.5	10.6

For the assessment of the effect of using advanced structures, weight reduction factors and cost factors were derived to reflect the use of advanced composite materials. In comparison to conventional aluminum structure, the purchased materials are costlier and the manufacturing costs slightly higher. These handicaps are overcome by reduced weight and its effect on size and power required. The results, expressed as percentage improvements, are listed in Figure 1.8.3.

The effects of advanced propulsion and airframe structure are combined to establish advanced technology baseline aircraft, with which to assess the impact of other factors. The results, expressed as percentage improvements over the present technology baseline aircraft, are listed in Figure 1.8.4. These improvements are substantial and emphasize the importance of applying advanced technology to future general aviation aircraft. The advanced technology configurations for Categories I, II, III and IV are shown in Figures 1.8.5, 1.8.6, 1.8.7 and 1.8.8, respectively.

FIGURE 1.8.4
COMBINED EFFECT OF ADVANCED PROPULSION
AND MATERIALS (ADV. TECHNOLOGY BASELINE AIRCRAFT)

CATEGORY PCT. IMPROVEMENT	I	II	III	IV
GROSS WEIGHT	14.5	22.0	18.2	32.7
MAX. H.P.	10.0	12.4	2.2	25.5
INITIAL COST	29.5	63.2	48.8	43.4
OPERATING COST *	17.0	31.0	15.8	27.4

* 300 hours per year utilization

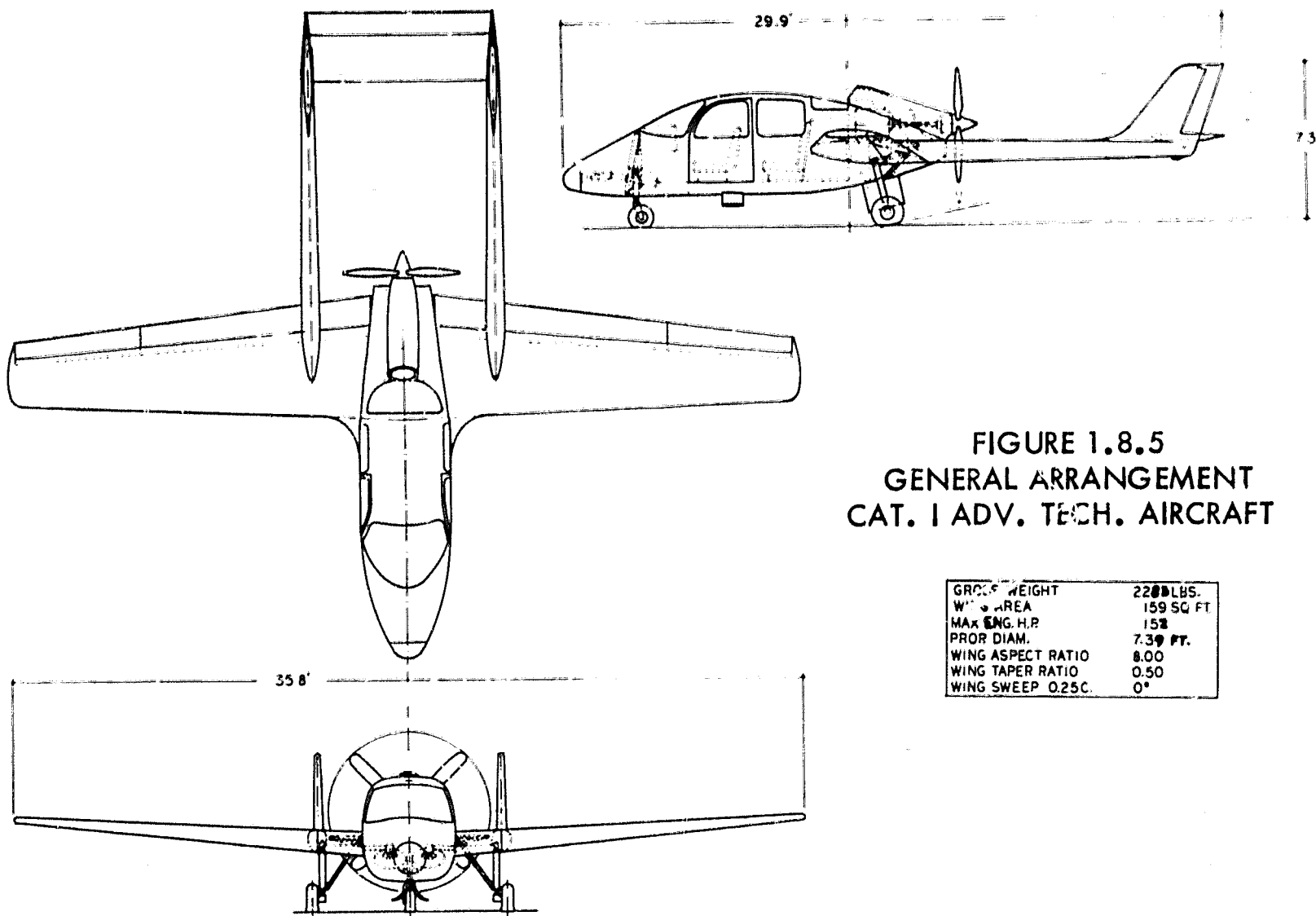


FIGURE 1.8.5
GENERAL ARRANGEMENT
CAT. I ADV. TECH. AIRCRAFT

GROSS WEIGHT	2200 LBS.
WING AREA	159 SQ. FT.
MAX. ENG. H.P.	152
PROP. DIAM.	7.39 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP	0.25C 0°

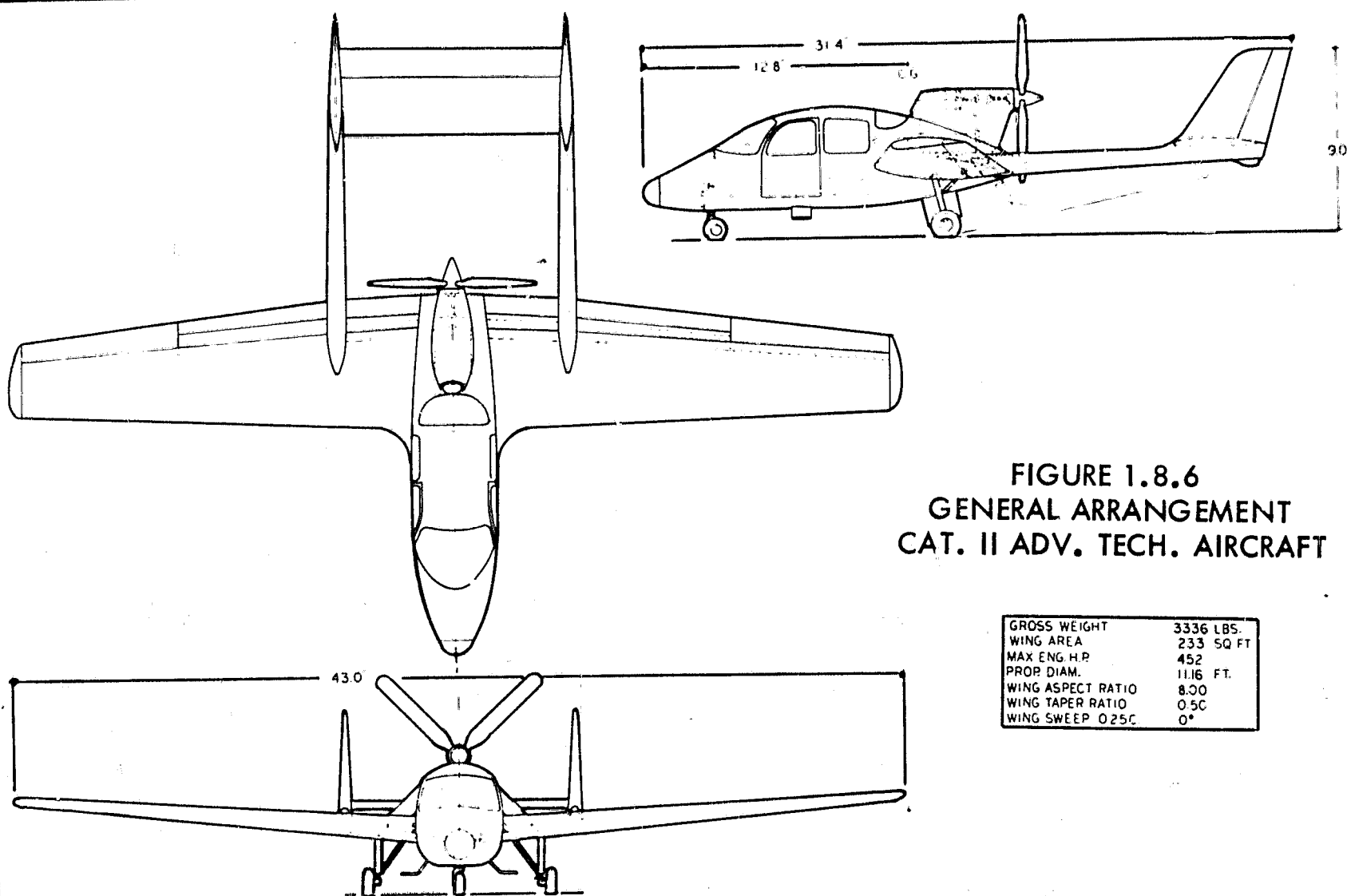


FIGURE 1.8.6
GENERAL ARRANGEMENT
CAT. II ADV. TECH. AIRCRAFT

GROSS WEIGHT	3336 LBS.
WING AREA	233 SQ. FT.
MAX. ENG. H.P.	452
PROP. DIAM.	11.16 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP	0.25C 0°

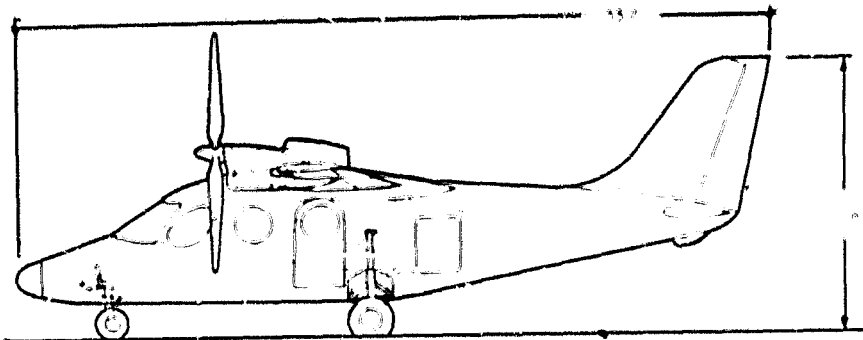
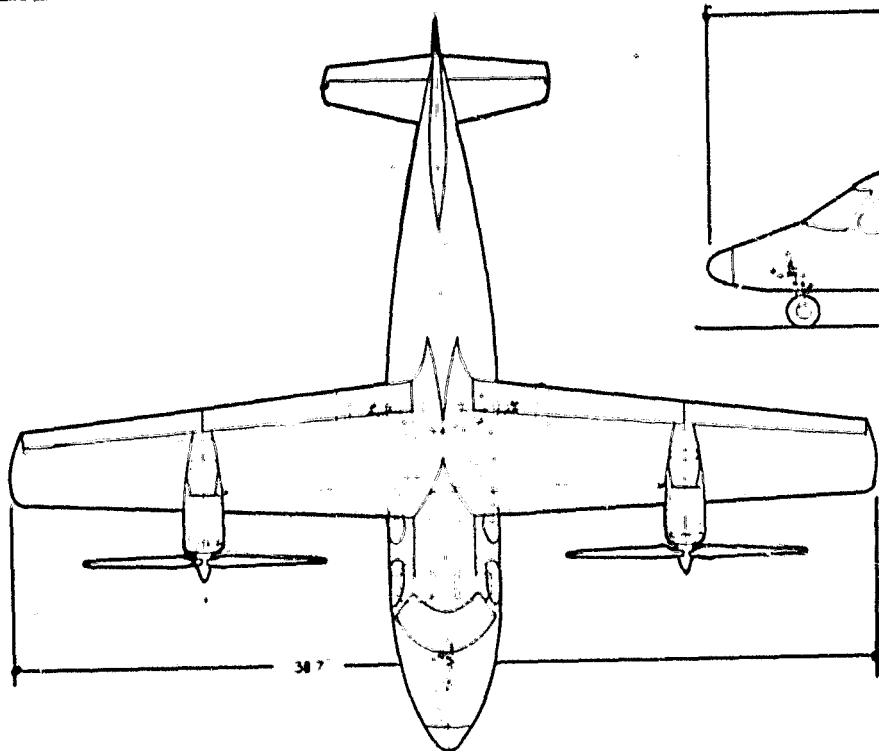


FIGURE 1.8.7
GENERAL ARRANGEMENT
CAT. III ADV. TECH. AIRCRAFT

GROSS WEIGHT	7538 LBS.
WING AREA	188.50 SQ. FT.
MAX ENG. HP	500
PROP. DIAM.	15.1 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP 0.25 C	0°

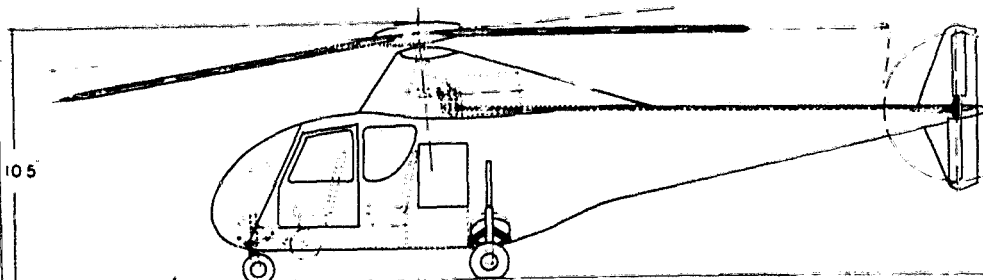
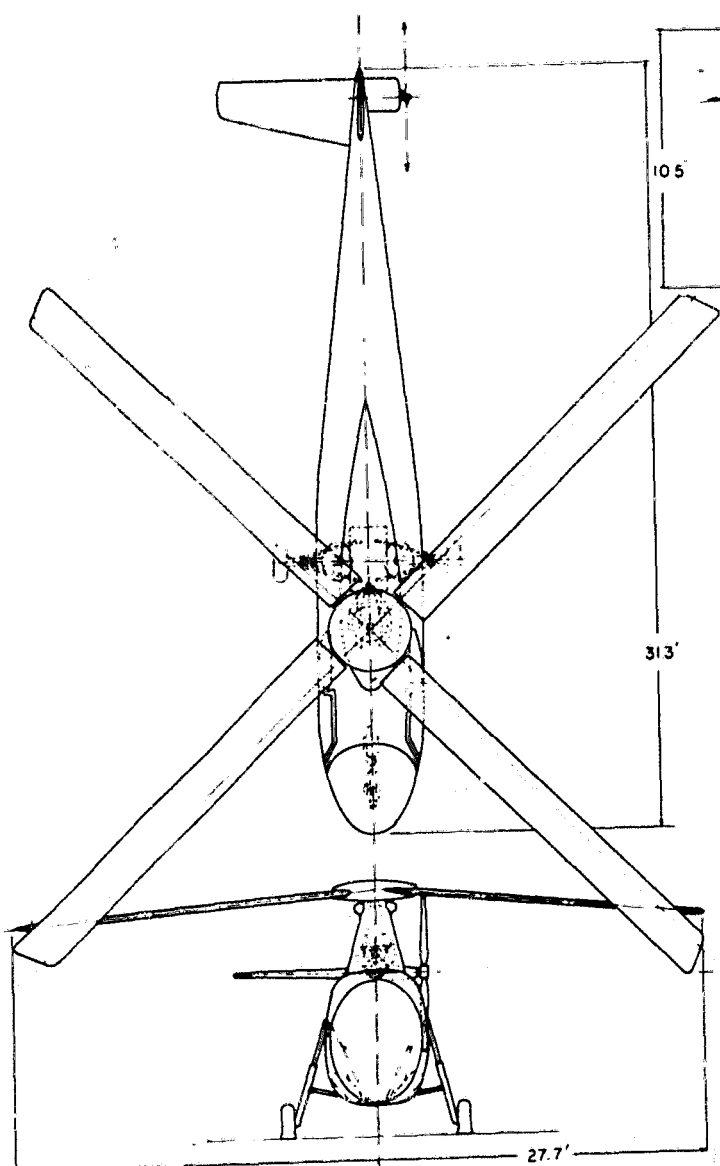
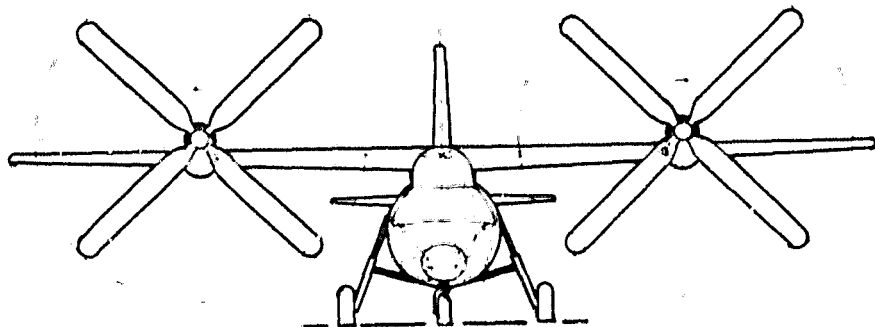


FIGURE 1.8.8
GENERAL ARRANGEMENT
CAT. IV ADV. TECH. AIRCRAFT

GROSS WEIGHT	3804 LBS.
MAIN ROTOR DIAM.	37.75 FT.
DISC LOADING	3.4 LBS./SQ. FT.
ROTOR SOLIDITY	0.10
MAX ENGINE H.P.	477

FIGURE 1.8.9.
CATEGORY I COMPARISON: FOLDABLE WINGS & ROADABILITY
(ADVANCED TECHNOLOGY VERSIONS)

	<u>BASELINE</u>	<u>TOWABLE</u>	<u>AUTOMOTIVE</u>
GROSS WEIGHT (LBS)	2285	2350	2670
MAX. ENGINE H.P.	152	156	178
CRUISE SPEED (KTS)	145	140	140
INITIAL COST (\$)	15,600	14,400	18,250
OPERATING COST (300 HRS/YR) (\$/MILE)	0.11	0.12	0.14

1.8.3 Alternate Configurations

Alternate configurations investigated in this study include the following: the roadable airplane in Category I; the autogyro in Category II; and the effect of turbofan propulsion in Category III.

The roadable configurations in Category I include foldable wings to facilitate home storage and to permit towability on the road. Automotive capability, using an auxiliary power unit to drive the wheels, was also assessed. A comparison of both versions with the advanced technology baseline aircraft is tabulated in Figure 1.8.9. A high wing tractor propeller configuration, with fixed landing gear and wings which fold backward in the horizontal plane was evaluated.

The autogyro was not considered as a baseline candidate in Category II. Although it can approach the vertical performance of the helicopter, it is not a true VTOL aircraft and hence must be considered in the STOL category. It is, however, capable of a "jump" takeoff and a flared landing without substantial ground roll. In this analysis, it was tailored to the 500 ft. field length by using that distance for climbout over the obstacle, following a jump takeoff. Advanced propulsion and materials technology were applied. A comparison with its fixed wing counterpart is tabulated in Figure 1.8.10. The calculated price is higher by a factor of 4.6, which reflects the higher cost per pound of rotary wing hardware. This includes components of the rotor system and the transmission, as well as the authorization of costly research and development programs over a comparatively small number of production aircraft.

FIGURE 1.8.10
CATEGORY II COMPARISON: FIXED WING VS. AUTOGYRO
(ADVANCED TECHNOLOGY VERSIONS)

		<u>FIXED WING</u>	<u>AUTOGYRO</u>
GROSS WEIGHT	(LBS)	3,336	4,000
MAX. ENGINE H.P.		452	397
INITIAL COST	(\$)	45,000	207,000
OPERATING COST (300 HRS/YR) (\$/MILE)		0.84	0.93

The 6-place aircraft of Category III is designed for long cruise range (1500 miles) and high cruising speed (250 knots). The application of turbofan propulsion was analyzed to assess the cost of attaining even higher speed. In order to minimize the initial cost, a single turbofan engine was used, since the cost per pound of thrust decreases considerably with the increase of rated thrust. Also, the reliability of the turbofan engine has already been established at a much higher level than that of a displacement engine/propeller combination. The general arrangement of this airplane is shown in Figure 1.8.11 and its comparison with a twin engine/propeller aircraft is tabulated in Figure 1.8.12, with both airplanes cruising at 20,000 ft. The optimum cruise speed of the turbofan aircraft is 300 kts and might be faster at a higher altitude. Its price is 65% higher, although its operating cost is only 4% higher. Despite the cost handicap, the turbofan approach should appeal to a large segment of potential corporate aircraft users.

1.8.4 Avionics and Subsystems

This division of the sensitivity analyses includes avionic systems, extra safety features and pressurization (in combination with high altitude operation).

The baseline aircraft (both present and advanced technology versions) do not include avionics equipment. This is in keeping with the present policy of general aviation aircraft manufacturers, whose basic prices are exclusive of avionics. For the assessment of advanced avionics, equipment lists were compiled for each category of airplane.

The equipment for Category I is selected for VFR operation in controlled airspace. It includes VHF communication, VOR/DME navigation with an Area Navigation computer, and an ATC transponder. The equipment is estimated to weigh 40 lbs. and cost \$6,000 installed.

The equipment selected for Category II, and which is also assessed for Categories III and IV, permits minimum capability IFR operation. It includes VHF communication; VOR/ILS/DME navigation with an Area Navigator computer; ADI/HSI displays; an autopilot/flight director; and an ATC transponder. The equipment is non-redundant, is estimated to weigh 70 lbs., and cost \$17,500 installed.

Categories III and IV are also assessed for the installation of equipment which permits maximum capability IFR operation equivalent to that of the airlines. It provides dual redundancy in the communication and navigation equipment of Category II; electronic attitude and horizontal situation displays; an autopilot/flight director; an ATC transponder; weather radar and a collision avoidance system. This equipment is estimated to weight 150 lbs. and cost \$48,000. It is designated "A" and the Category II equipment is designated "B" for assessment in Categories III and IV.

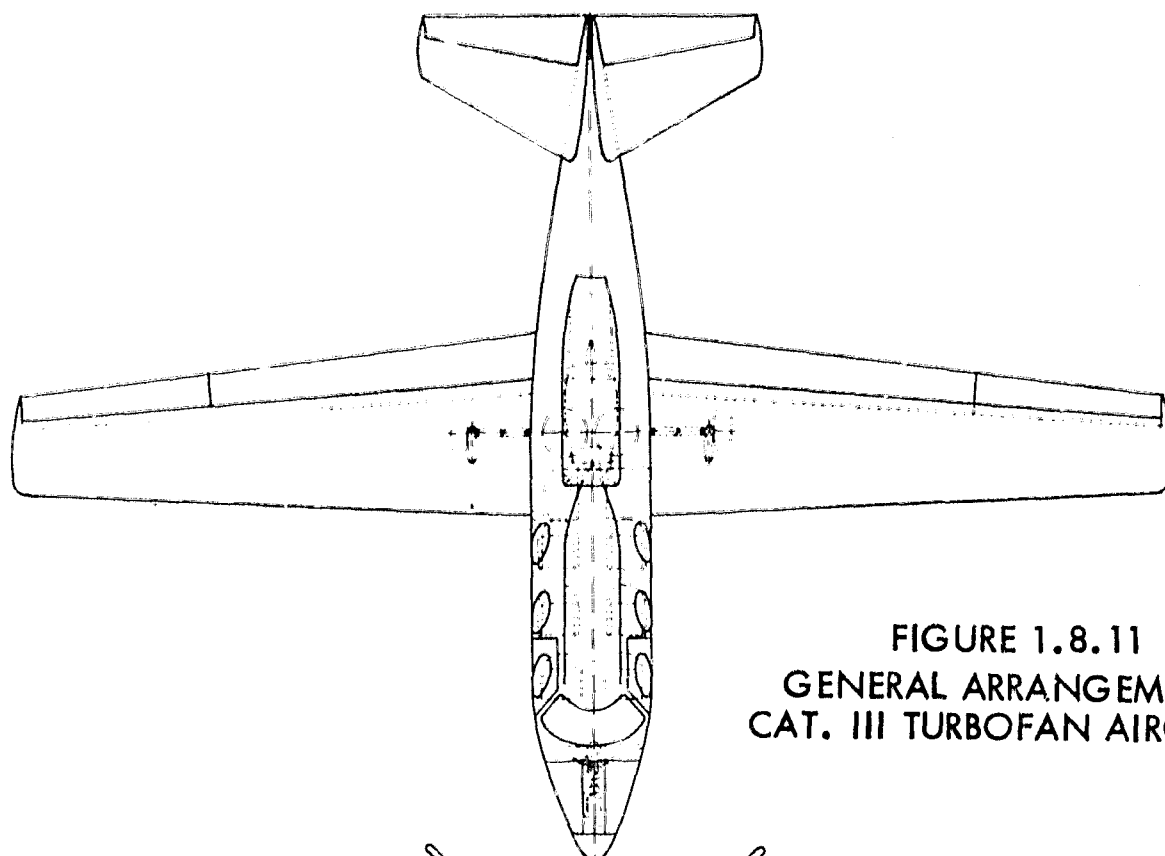
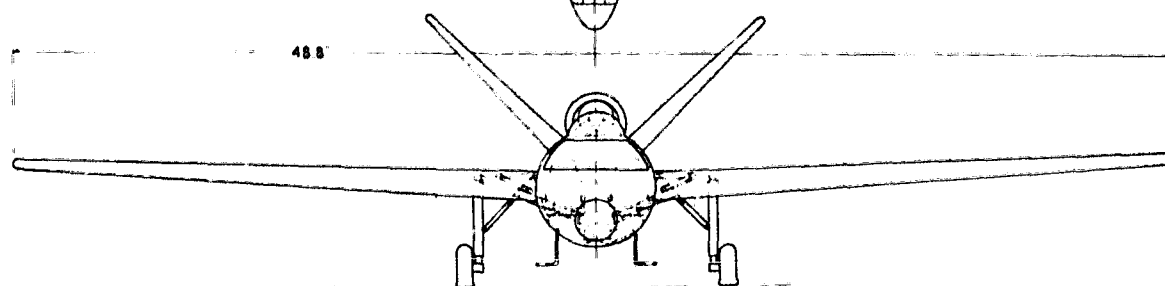


FIGURE 1.8.11
GENERAL ARRANGEMENT
CAT. III TURBOFAN AIRCRAFT



GROSS WEIGHT 8776 LBS
WING AREA 296 SQ FT
MAX. ENG. THRUST 2875 LBS
WING ASPECT RATIO 8.00
WING TAPER RATIO 0.50
WING SWEEP 0.25C 0°
BAGGAGE SPACE 24 CU FT

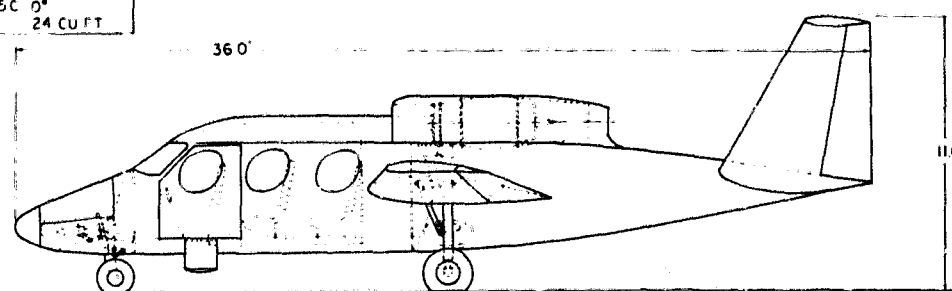


FIGURE 1.8.12

CATEGORY III COMPARISON: PROPELLERS VS. TURBOFAN

(ADVANCED TECHNOLOGY VERSIONS; 20,000 FT. CRUISE ALT.; 85 PNdb AT 500 FT.)

		2 ENGINE/PROP.	SINGLE TURBOFAN
GROSS WEIGHT	(LBS)	6,624	8,776
MAX. H.P. OR THRUST	(LBS)	756 (HP)	2,875 (LBS)
CRUISE SPEED	(KTS)	250	300
INITIAL COST	(\$)	136,200	207,300
OPERATING COST (300 HRS/YR)	(\$/MILE)	0.51	0.53
Noise Level @500 ft. (PNdb)		75	85

FIGURE 1.8.14

EFFECT OF ADVANCED AVIONICS AND
AUTOMATIC FLIGHT CONTROL

CATEGORY	I	II	III		IV	
ALTERNATES			A	B	A	B
PCT. INCREASE IN:						
GROSS WEIGHT	3.2	3.9	3.8	1.7	9.4	4.2
MAX H.P.	2.0	1.6	2.0	0.8	6.7	2.9
INIT. COST	38.5	38.9	32.0	10.1	39.6	11.4
OPER. COST *	31.2	12.2	6.8	3.0	18.0	6.5

* 300 HRS/YR UTILIZATION

Figure 1.8.14 shows the effect of providing these equipment packages in the four categories of aircraft. The results are expressed as percentage increases over the listed characteristics of the advanced technology baseline aircraft. The percentage cost increases can be compared to a range of 25 to 30% over the basic price of the aircraft, which reflects the average cost of avionics in present day general aviation operation.

The extra safety features assessed here provide a level of safety over and above that required by FAA regulations. They are divided into two categories: structural and systems. The structural category includes a 9 g maneuver load factor, a 13 ft/sec rate of sink and a crash-resistant cabin structure, designed to sustain impact velocities up to 30 ft/sec and vertical accelerations to 15 g without seriously injuring the occupants. The systems category includes anti-icing, lateral stabilization, automatic landing flare, crash locator beacon, remote fuel tanks and a fire-retardant system for the fuel. While the two categories have been assessed both separately and in combination, only the total effect is shown in Figure 1.8.15, again expressed as percentage increases over the listed characteristics of the basic advanced technology aircraft. The results appear to be overly penalizing in Categories I and II, but reasonable in the other two categories, especially IV. Corporate users may be willing to pay the difference. The effect on insurance rates have not been included for lack of specific information. A 50% rate reduction would bring about, approximately, a 10% reduction in operating cost.

FIGURE 1.8.15
EFFECT OF EXTRA SAFETY PROVISIONS
(ADVANCED TECHNOLOGY AIRCRAFT)

CATEGORY PCT. INCREASE	I	II	III	IV
GROSS WEIGHT	25.5	36.2	24.3	10.7
MAX. H.P.	16.5	23.9	12.8	7.8
INITIAL COST	71.0	75.0	50.5	15.9
OPER. COST *	32.2	37.1	18.7	8.7

Cabin pressurization and high cruise altitude features are applied by providing a cabin of circular cross-section in combination with the installation of turbochargers on the engines. It is assumed that this would be a minimum capability pressurization system consisting of a turbocharger with an inter-cooler and appropriate controls, a pressurized fuselage and a regulator. Low altitude refrigeration is not provided. Application to Category IV is not assessed, because the low rotor speed of the helicopter would lead to retreating blade stall in low density air. Figure 1.8.16 tabulates the effect on the basic advanced technology aircraft characteristics, expressed in terms of percent increase or decrease. It is wholly beneficial for Category II and III aircraft and marginally so in Category I. The reduced wing loading required for optimization, however, requires a 47% increase in wing area, which complicates ground handling and storage, and increases gust sensitivity. The results reflect the dominating influence of reduced engine power and fuel consumption in opposition to the added weight and cost of structure and equipment.

FIGURE 1.8.16
EFFECT OF PRESSURIZATION AND HIGH ALTITUDE CRUISE
(ADVANCED TECHNOLOGY AIRCRAFT)

CATEGORY PCT. INCREASE	I	II	III
GROSS WEIGHT	2.4	-1.9	-14.6
MAX. H.P.	-12.5	-18.8	-24.4
INITIAL COST	2.6	-7.1	-20.9
OPER. COST *	-5.4	-13.1	-15.0

* 300 Hrs/Yr Utilization

FIGURE 1.8.17

EFFECT OF NOISE LEVEL ON PRICE

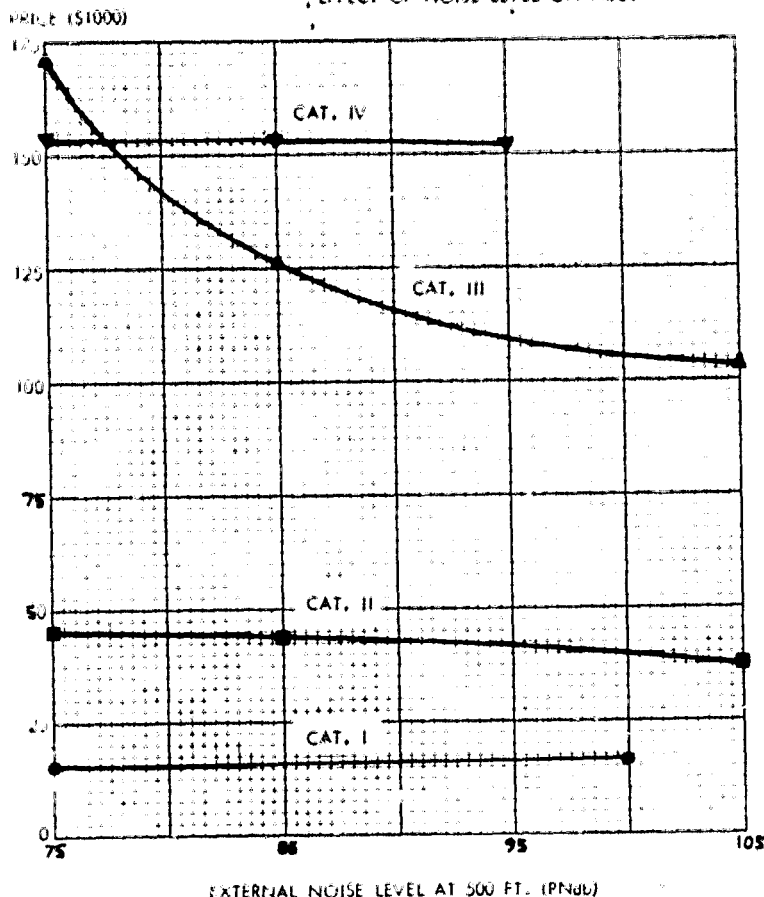
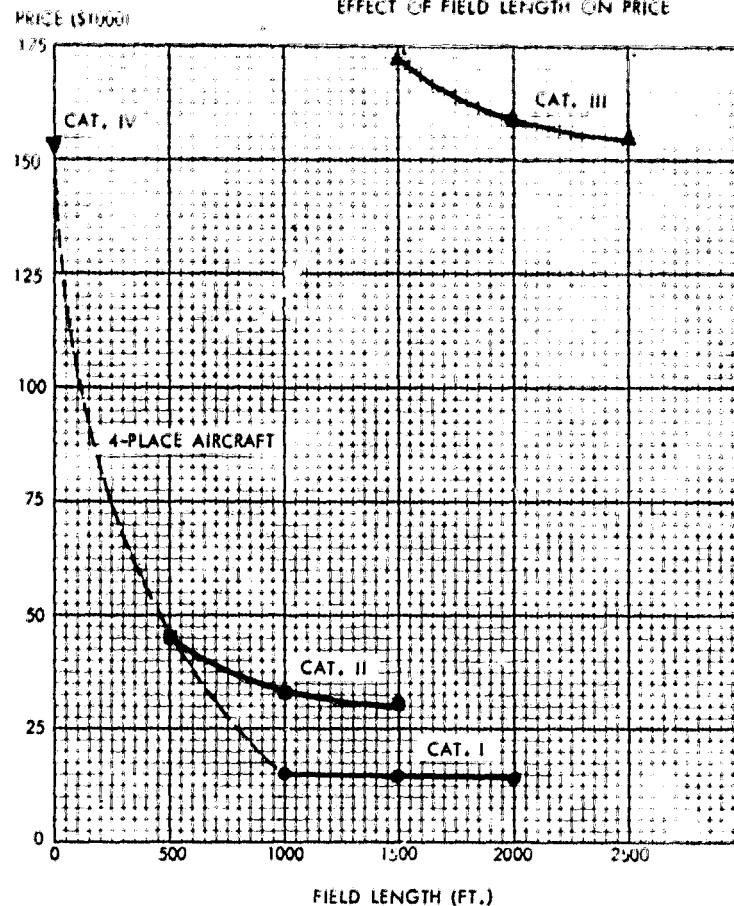


FIGURE 1.8.18

EFFECT OF FIELD LENGTH ON PRICE



1.8.5 Performance Variables

These assessments include variations of external noise level, field length, cruise speed, cruise range, and payload capacity.

The standard noise constraint of this study is 75 PNdB at 500 ft. and is believed to represent a practical level. To assess the penalties, if any, due to quiet operation, propellers were selected for performance without regard to noise, and an intermediate level of 85 PNdB was assessed. Figure 1.8.17 shows the effect of external noise level on price. It is relatively insensitive to the aircraft of Categories I and IV, mildly sensitive in Category II and very sensitive in Category III. This effect is in line with operational considerations. Aircraft in Categories I, II and IV would operate in an out of close-in airfields, while those in Category III would use major and satellite airports, where a higher noise level would be tolerated.

The required field lengths are 0, 500, 1000 and 1500 ft. for Categories IV, II, I and III respectively. Figure 1.8.18 shows the effect of field length on price, with variations within Categories I, II and III. The Category I aircraft is insensitive, but those of Categories II and III are substantially affected. The "intercategory" dashed curve connecting the minimum field length points of Categories I, II and IV, illustrates the effect of field length on the price of 4-place aircraft, showing a sharp rise below 1000 ft. This curve is not truly representative, since the aircraft of Categories I, II and IV are designed for different cruise speeds. For instance, at the same field lengths, the higher cost of Category II aircraft over those of Category I reflects higher cruise speed performance.

FIGURE 1.8.19

EFFECT OF CRUISE SPEED ON PRICE

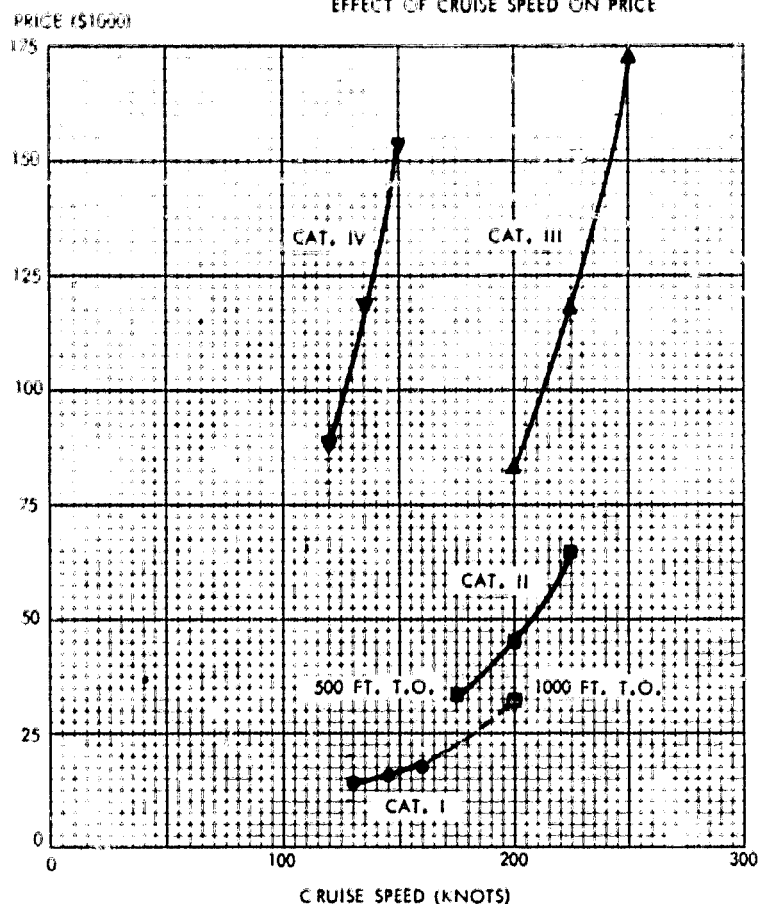
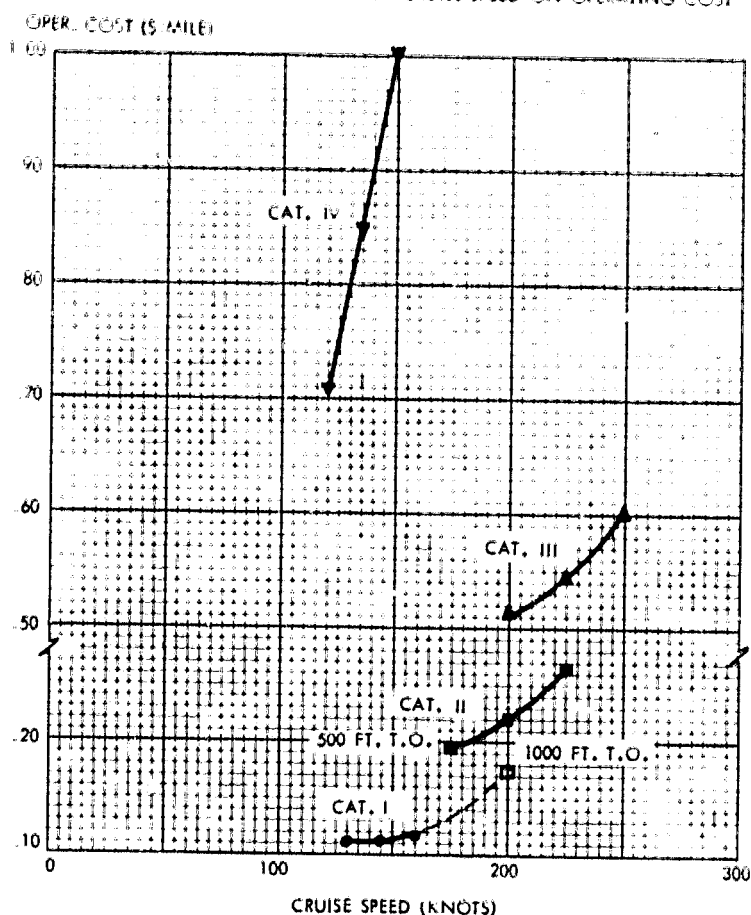


FIGURE 1.8.20

EFFECT OF CRUISE SPEED ON OPERATING COST

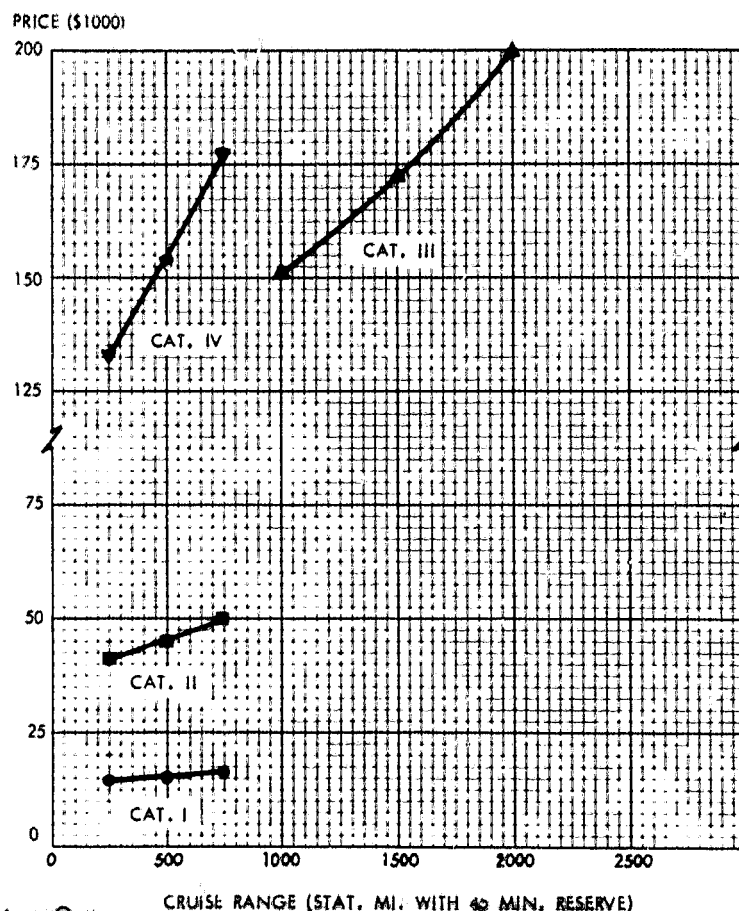


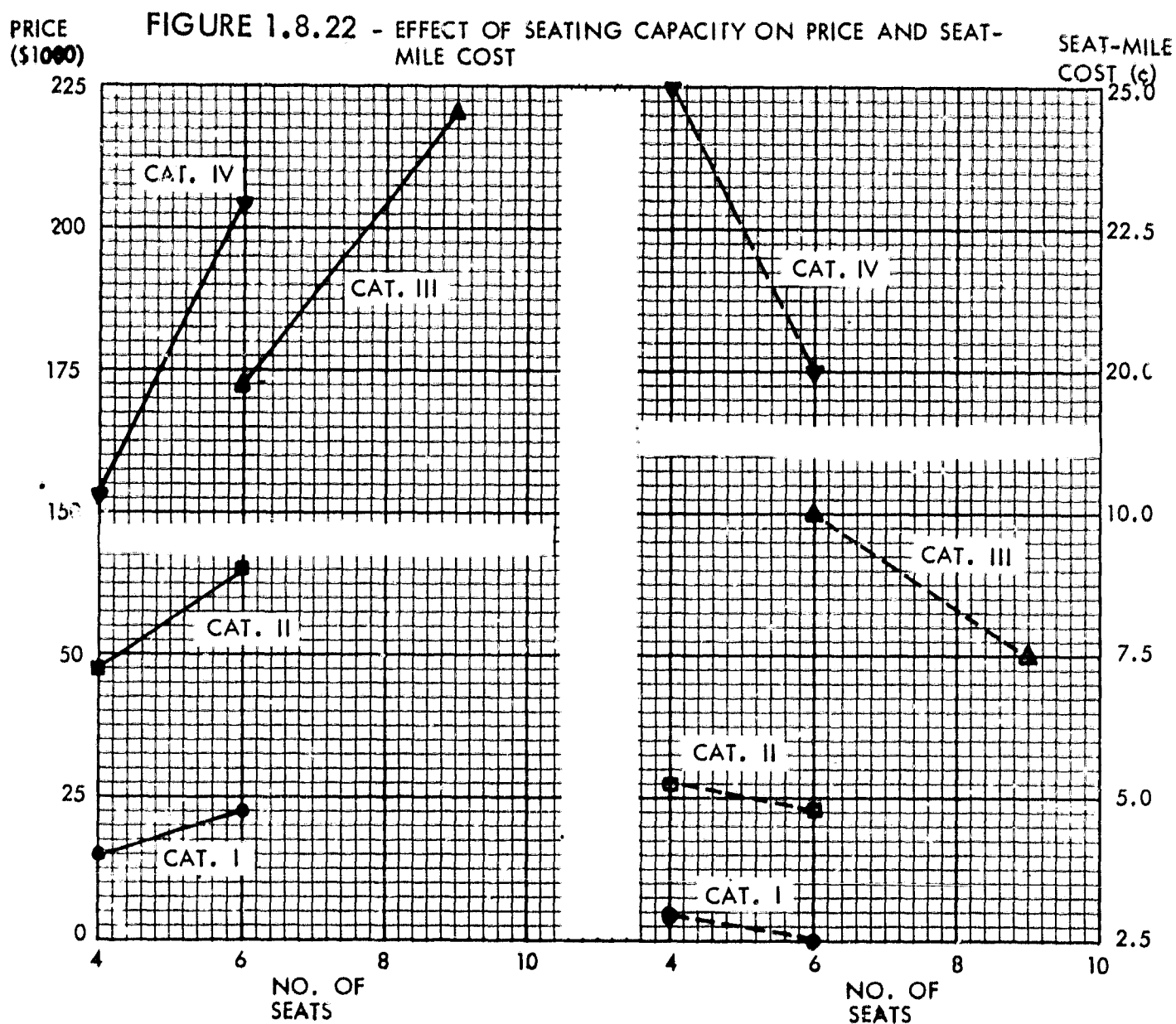
The price of aircraft in all categories are very sensitive to design cruise speed, as shown in Figure 1.8.19. Category I, however, is relatively insensitive between 130 and 160 knots. The curves of Categories III and IV are nearly asymptotic at the study requirement values. Figure 1.8.20 shows the effect of cruise speed on operating cost, showing similar trends and maximum sensitivity in Category IV.

Figure 1.8.21 shows the effect of cruise range on price. Sensitivity varies with the numerical order of the categories in much the same manner as cruise speed. None, however, appear to be range-limited within the limits investigated.

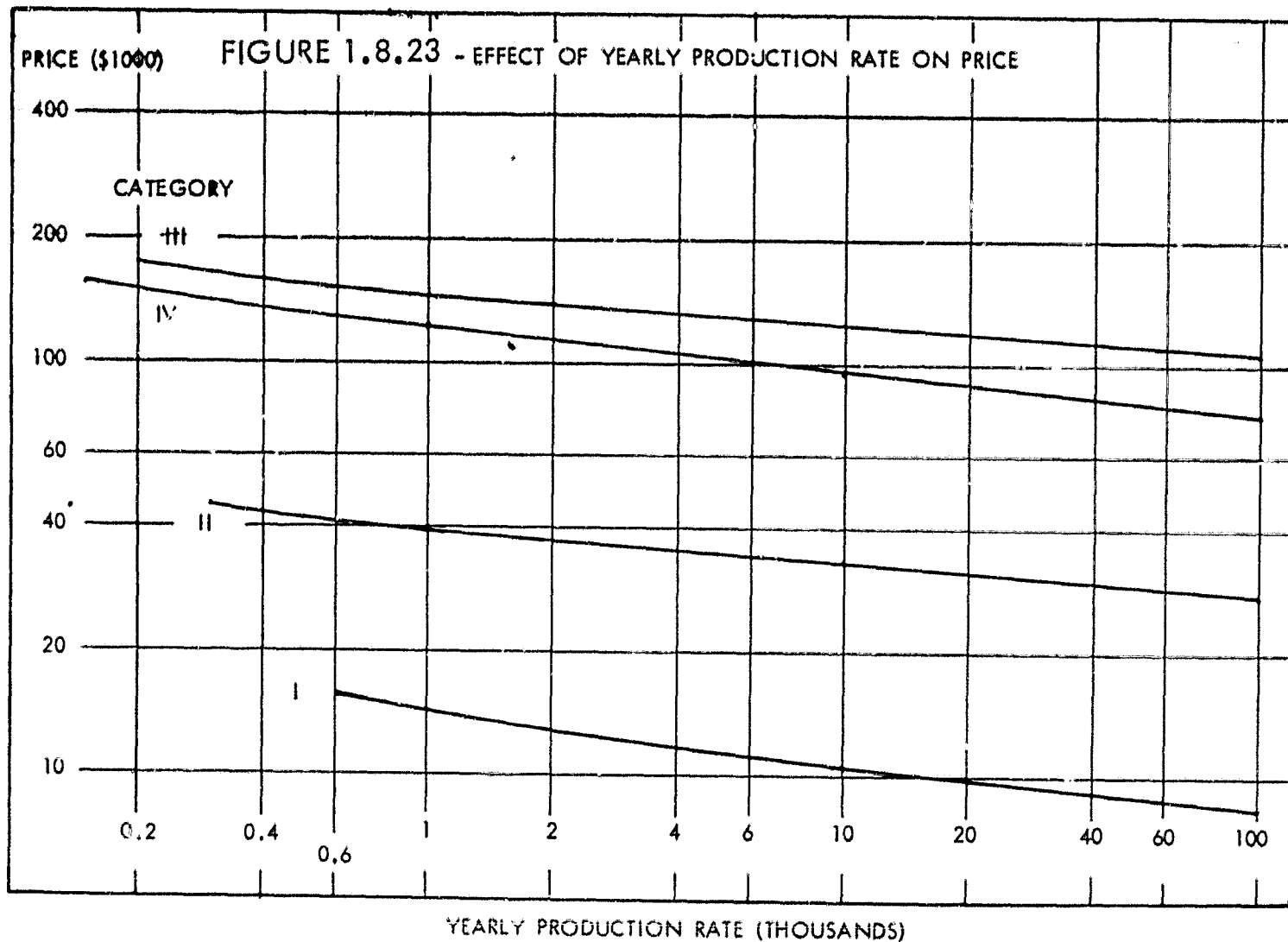
FIGURE 1.8.21

EFFECT OF CRUISE RANGE ON PRICE





Each advanced technology, basic aircraft design was assessed for a 50% increase in seating capacity. This was accomplished by lengthening the fuselage of aircraft, in Categories I, II and III and widening it for 3-abreast seating in Category IV. In Figure 1.8.22, the effect on price is shown by the solid lines, and on seat-mile operating cost by the dashed lines. The latter effect is meaningful to business aircraft owners and shows that Category I aircraft offer the lowest personal transportation rates, followed by II, III and IV aircraft in that order. If the straight lines were extrapolated, they would show that 14 seats in aircraft of Categories II and III, and 11 seats in aircraft of Category IV, would be required to meet the seat-mile cost of Category I 4-place aircraft. The differences reflect increased performance and complexity.



1.8.6 Increased Production

Figure 1.8.23 shows the impact of yearly production rate on price. The lowest rates shown on the chart represent typical current rates, which were used to determine the initial cost of the present and advanced technology aircraft of this study. Category I aircraft prices drop by 46% between rates of 600 and 100,000. Those of Category II drop by 40% between rates of 300 and 100,000. Those of Category III drop by 37% between rates of 200 and 100,000 and those of Category IV drop by 50% between 150 and 100,000 per year. Rates as high as 100,000 per year are probably not realistic for any single manufacturer, even for Category I aircraft in the 1985 time period. However, the drop in price due to volume stresses the importance of producing high performance, quiet, utilitarian aircraft design for low production cost.

FIGURE 1.8.24 EFFECT OF TECHNOLOGY & NOISE LEVELS ON PRICE VS WEIGHT-SPEED PRODUCT (EXCLUDING AVIONICS)

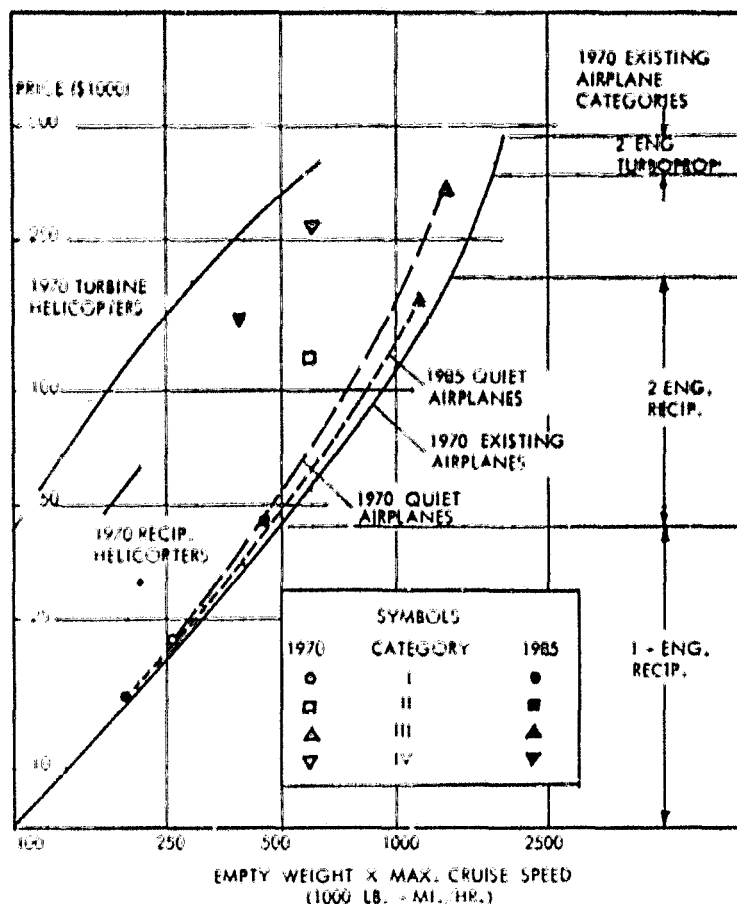
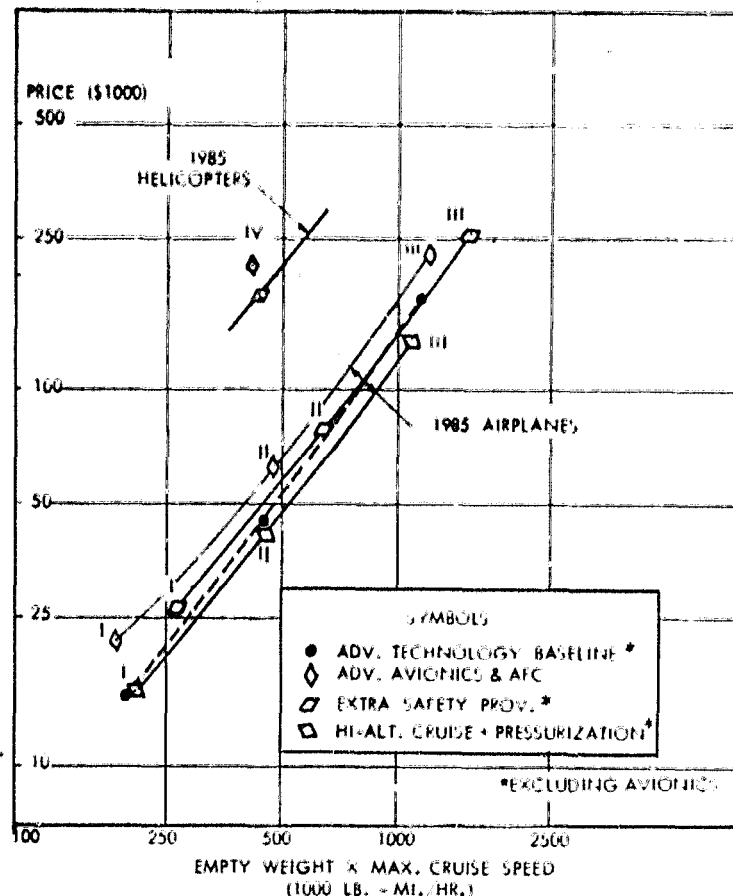


FIGURE 1.8.25 EFFECT OF ADDED PROVISIONS ON PRICE VS WEIGHT-SPEED PRODUCT (ADVANCED TECHNOLOGY AIRCRAFT)



1.8.7 Sensitivity Summary

The graph of Figure 1.7.2 showed the present cost trend of contemporary aircraft as a function of the weight-speed product. This trend is repeated in the graph of Figure 1.8.24, showing solid curves for contemporary airplanes and helicopters. The long dashed curve represents the present technology, quiet airplane derived in this study, which exact a higher price based on weight x speed. The short dashed curve, representing advanced technology quiet airplanes, lies between the other two. This shows that quiet airplanes (with also better air-field performance) cost slightly more, per pound-mph, than contemporary airplanes. The opposite effect is noted with helicopters and reflects the lower cost of rotating combustion engines as compared with turbines. No avionic equipment is included in this comparison.

Figure 1.8.25 shows a similar graph, confined to the advanced technology aircraft of this study, to show the effect of added provisions. The airplanes of Categories I, II and III are joined, while the helicopters of Category IV are isolated. The dashed curve, joining black dots, reflects the advanced technology baseline aircraft. The solid curve below represents those with high altitude capability, while the solid curve immediately above represents those with extra safety provisions. The foregoing curves do not include avionics. The highest curve for airplanes reflects the cost of advanced avionics and flight control, with the capability varying from VFR with accurate navigation aids in Category I, to minimum capability IFR in Category II and maximum capability IFR in Categories III and IV.

The effects brought out in the sensitivity analyses are instrumental in choosing the recommended configurations, which follow.

FIGURE 1.9.1
GENERAL ARRANGEMENT
CAT. I RECOMMENDED CONFIG.

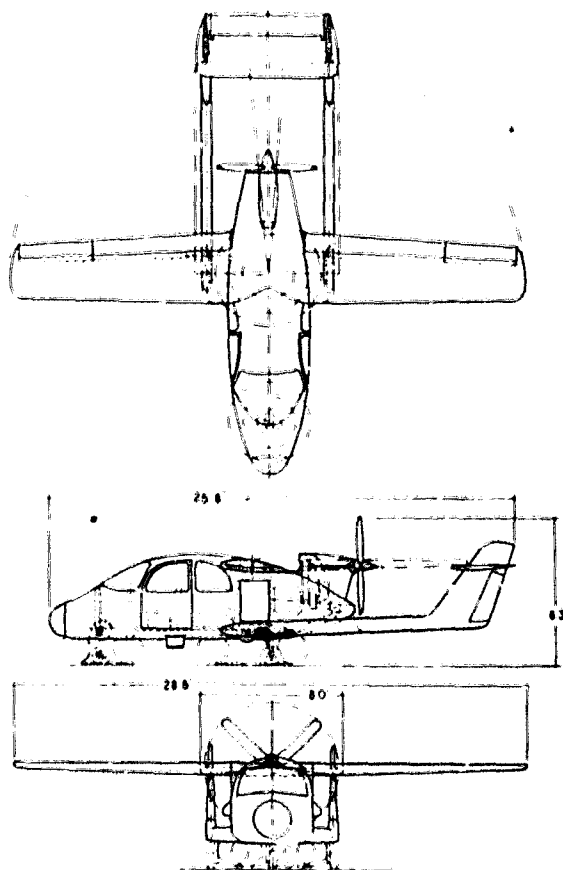
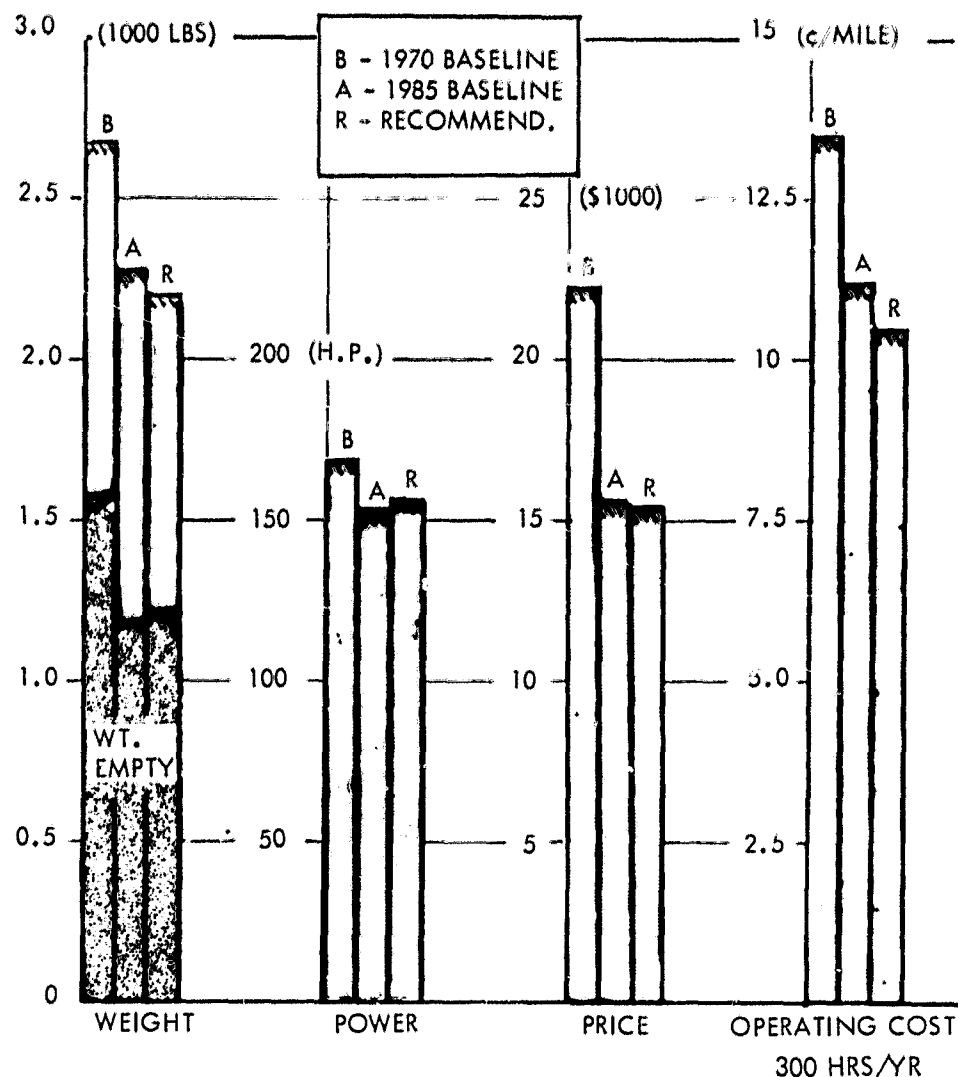


FIGURE 1.9.2 COMPARISON BETWEEN RECOMMENDED AND
BASELINE CONFIGURATIONS, CATEGORY I



1.9 Recommended Configurations

Tentative recommendations of promising aircraft configurations in each category are made by combining the results of the sensitivity analyses and reconfiguring the advanced technology baseline aircraft into designs which the investigators feel will provide the maximum stimulus to the use of general aviation in the future. This is one of the principal objectives of the study - the other being "how to get there."

1.9.1 Category I

Several combinations were examined in this category before a sound recommendation could be made. They included a combination of advanced avionics and extra system safety provisions, while retaining the same speed and range, but raising the field length to 1500 ft. The 75 PNdB noise level requirement was retained. This resulted in a price increase, with increased operating cost.

The logical direction to take in providing a privately owned airplane with increased popularity is to make it more useful to the owner. Therefore, the utility and convenience features brought out in the technology investigation were examined for application. It was found possible to combine the features of wing folding, towability and all-terrain capability with the pusher propeller configuration without serious compromise. The result is shown in Figure 1.9.1. In the area of performance, an extra 500 ft. of field length (to 1,500 ft.) and 100 miles less of range (to 400 miles) was traded for an extra 10 knots of cruise speed (to 155 kts or 178 mph). This results in a smaller, easily handled aircraft that can be "garaged" at home and towed to any available clearing or waterway for flight operation. Economically, the price is about the same and the operating cost is about 6% less. Figure 1.9.2 shows its comparison to the present and advanced technology baseline airplanes in Category I.

FIGURE 1.9.3
GENERAL ARRANGEMENT
CAT. II RECOMMENDED CONFIG.

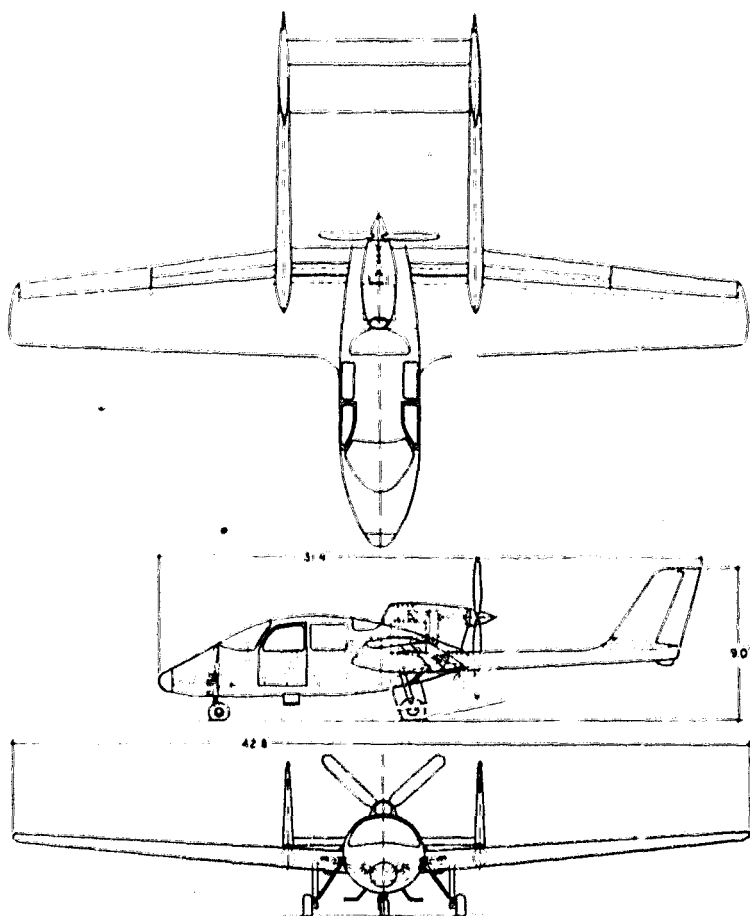
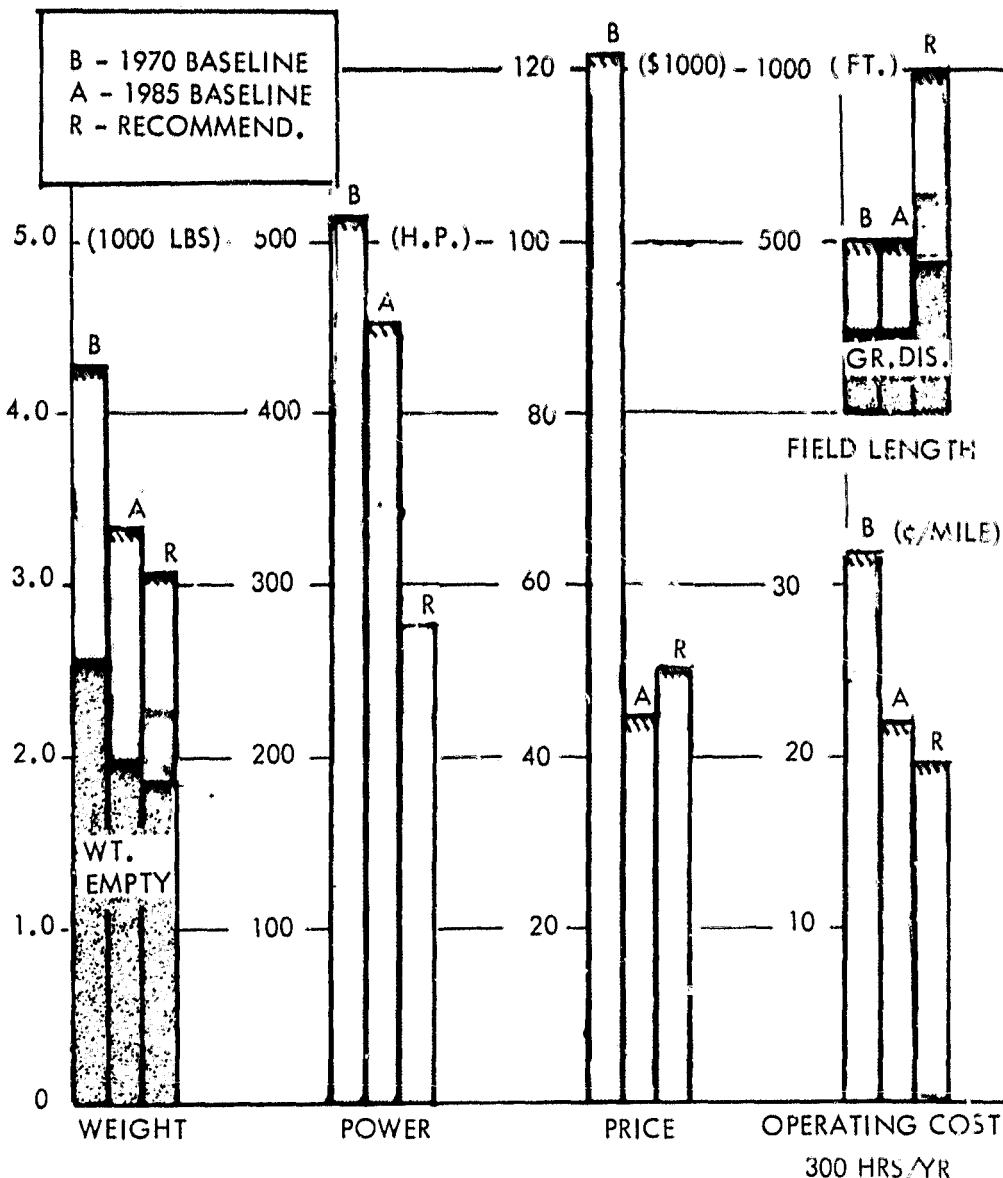


FIGURE 1.9.4 COMPARISON BETWEEN RECOMMENDED AND
BASELINE CONFIGURATIONS, CATEGORY II



1.9.2 Category II

This aircraft is classified as STOL, which implies operation between areas of dense population, to and from close-in airfields, as well as in "bush" country and from high altitude airfields. STOL performance, as such, has never been expressed in terms of a definite field length or minimum flight speed, both of which increase with the size and weight of the airplane. While a field length of 500 ft. was specified by NASA, it is believed that minimum length STOL strips are, and will continue to be, at least 1000 ft. in length to accommodate medium-to-large aircraft. Therefore, it was considered expedient to trade the extra 500 ft. for other desirable capabilities; namely, extra system safety provisions, advanced avionics and automatic flight control, with IFR capability. Another desirable feature is high altitude cruise capability, which was found to be a weight, power and cost reduction item. No compromises with range and noise level are recommended.

The resulting configuration is illustrated in Figure 1.9.3, and it is compared with the present and advanced technology baseline aircraft in Figure 1.9.4. The initial cost is only 11% higher than that of the 1985 baseline and is 59% lower than that of the 1970 baseline. The operating cost is lower than that of either. Although this airplane is priced in the realm of the business operator, it should be attractive to a small segment of private owners, as well. Its high degree of utility should result in higher-than-average utilization, with correspondingly lower operating costs.

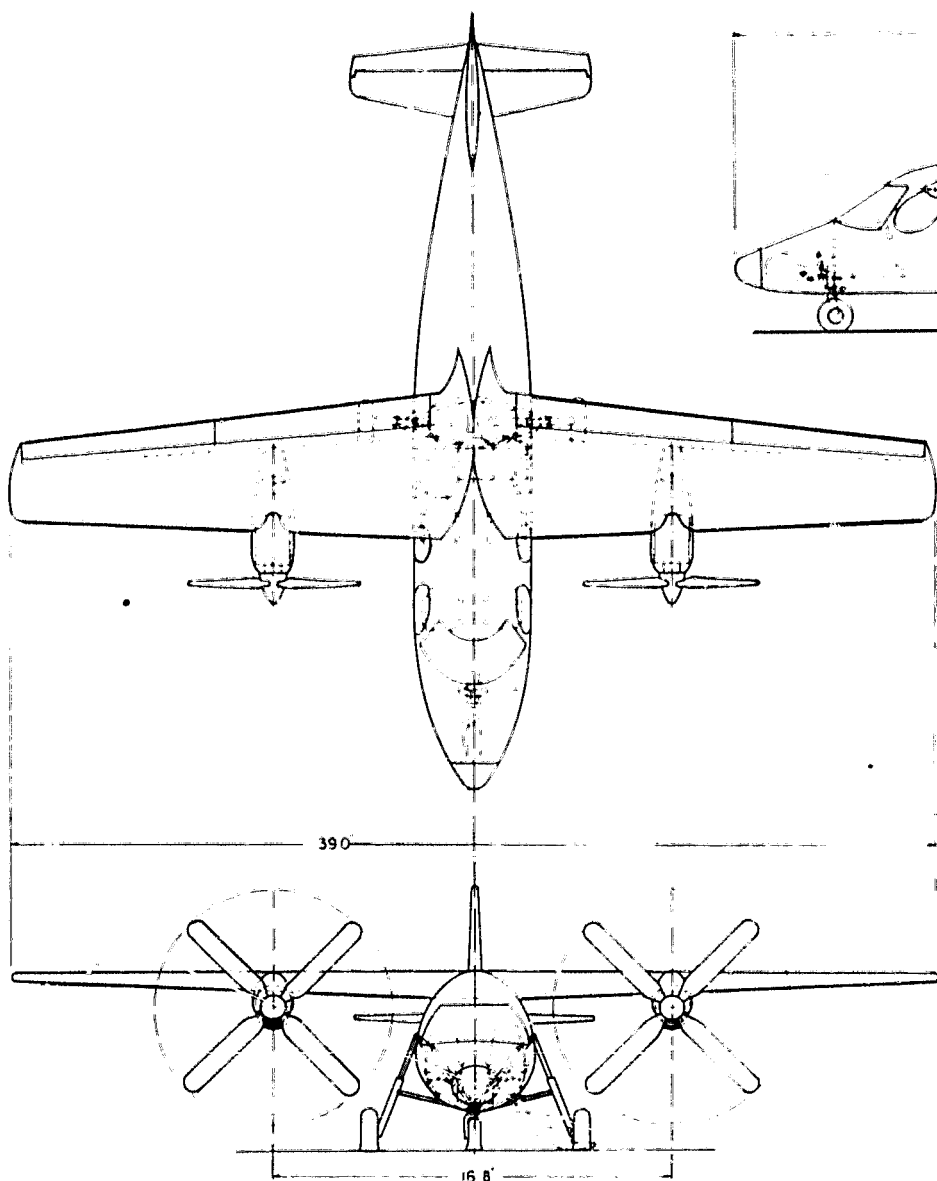


FIGURE 1.9.5
GENERAL ARRANGEMENT
CAT. III RECOMMENDED CONFIG.

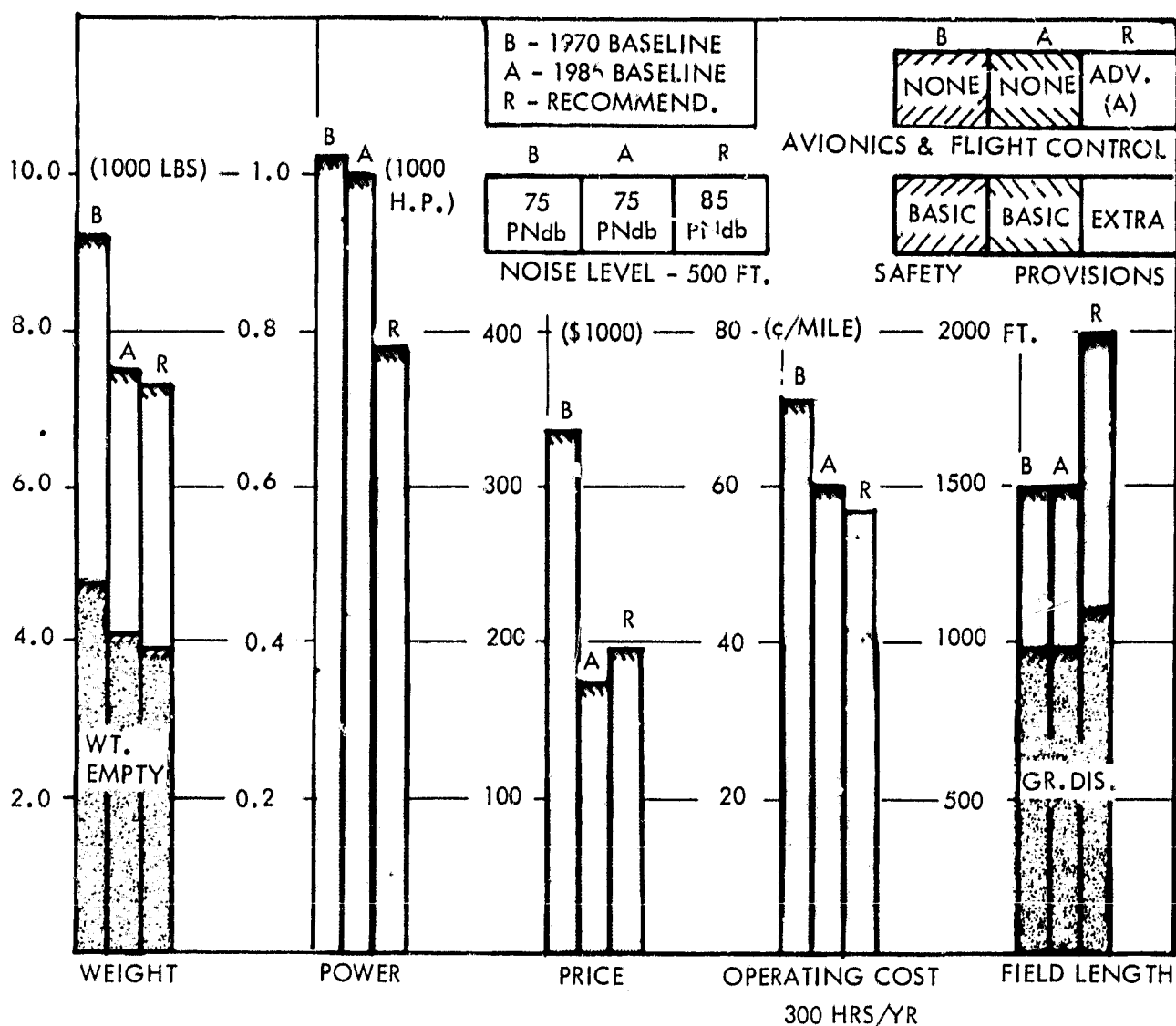
GROSS WEIGHT	7328 LBS
WING AREA	19750 FT ²
MAX ENGINE H.P.	390
PROPELLER DIAM.	9.98 FT
WING ASPECT RATIO	8.0
WING TAPER RATIO	0.50
WING SWEEP 0.25 C	0°

1.9.3 Category III

This airplane is designed for the corporate owner in the medium-to-large business bracket. His requirements call for long range operation at high cruising speeds, use of medium length airstrips, a comfortable interior -- but, above all, a high degree of schedule reliability with maximum independence of weather.

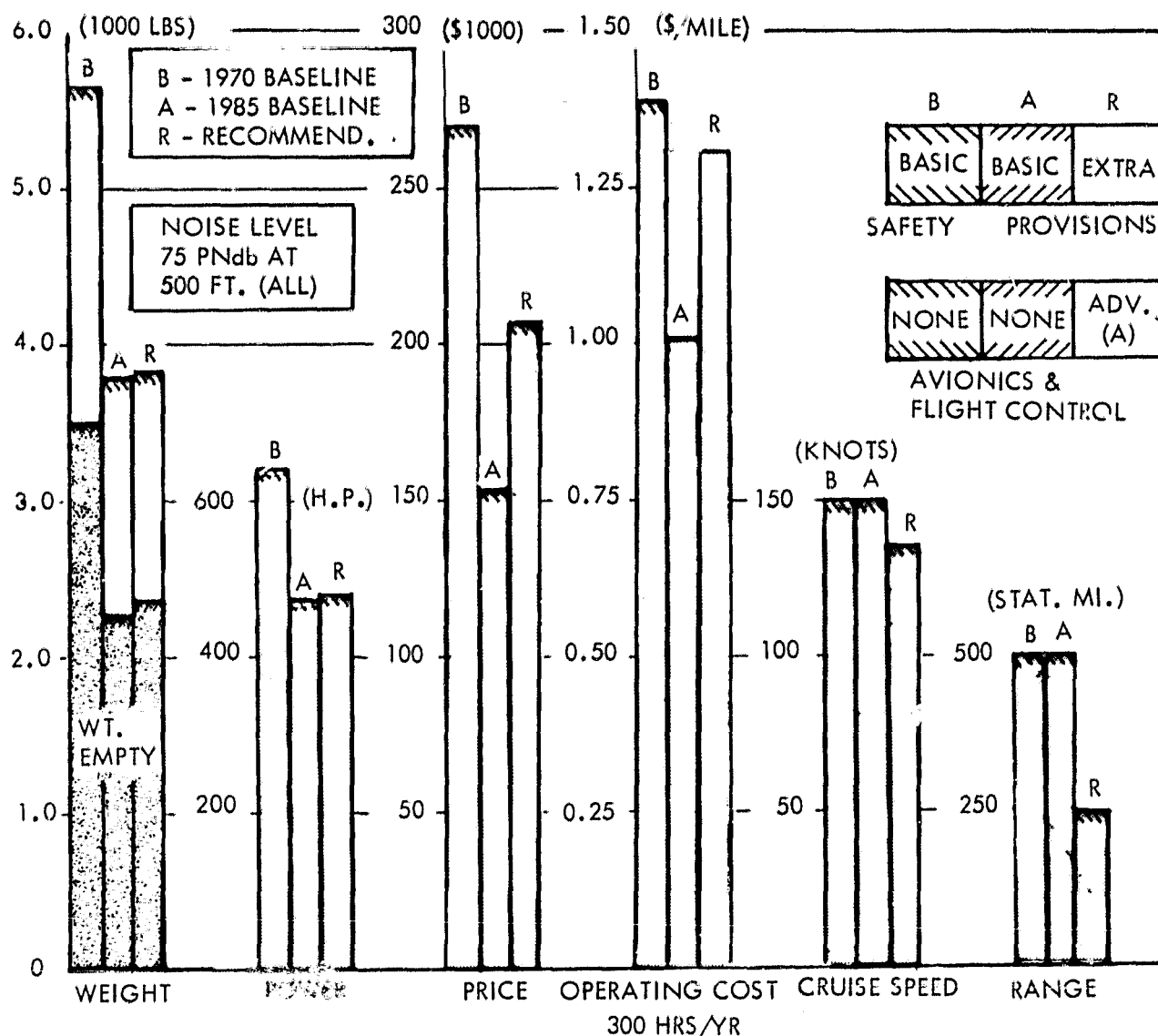
The principal objection to the baseline aircraft in Category III is the abnormally large propellers. The propeller diameter can be reduced to an acceptable size by raising the external noise level and increasing the field length. Increments of 10 PNdB and 100 ft., respectively, result in a level of 85 PNdB and a 2000 ft. field length, which are compatible with the satellite airfields from which the majority of operation would occur. Trading these increments for advanced avionics and flight control, plus extra structural and system safety provisions, results in the compact, attractive configuration shown in Figure 1.9.5. It is compared with the present and advanced technology baseline aircraft in Figure 1.9.6, which shows competitive price and operating cost with respect to the latter.

FIGURE 1.9.6 COMPARISON BETWEEN RECOMMENDED AND BASELINE CONFIGURATIONS, CATEGORY III



Increasing the noise level to 85 PNdb admits reconsideration of the turbofan candidate described in Section 1.8.6, which provides a 20% increase in cruise speed. In comparison to the recommended propeller aircraft, it lacks the advanced avionics and extra safety provisions, costs 5.5% more to buy and 26% more to operate. Inclusion of these items would widen the cost gap considerably. Nevertheless, the turbofan or perhaps a compromise "prop-fan" design might appeal to a considerable segment of the market.

FIGURE 1.9.7 COMPARISON BETWEEN RECOMMENDED AND BASELINE CONFIGURATIONS, CATEGORY IV



1.9.4 Category IV

The helicopter configuration, selected for Category IV, is designed primarily for the business owner whose principal transportation problem is rapid transit, within a metropolitan area or between closely spaced areas of dense population. He would like to dispense with ground travel altogether, making use of "heli-pads" on roof tops, in city parks and other convenient locations including parking lots. To become fully accepted by the public, the aircraft must have a low external noise level. To be fully useful to the operator, it must have all-weather capability and extra safety provisions - the latter being due to flight in a forest of obstacles. The operator should be willing to accept a slightly lower cruise speed and possibly a shorter range in trade for the additional provisions, since these characteristics will not seriously impede his operations. Operation at longer ranges, such as between the parking lots of industrial plants, might be desirable, however.

The recommended configuration trades a 15 knot reduction in cruise speed (to 135 kts) and a 250 mile reduction in range (to 250 miles) for the advanced avionics, automatic flight control and extra safety features. It results in a craft of the same size as that of the advanced technology baseline, hence Figure 1.8.8 is applicable. Its comparison with that design shows a 36% higher price and 30% higher operating cost, though the latter might become lower due to higher utilization.

FIGURE 1.10.1

PAST & PROJECTED GENERAL AVIATION AIRCRAFT DELIVERIES PER YEAR

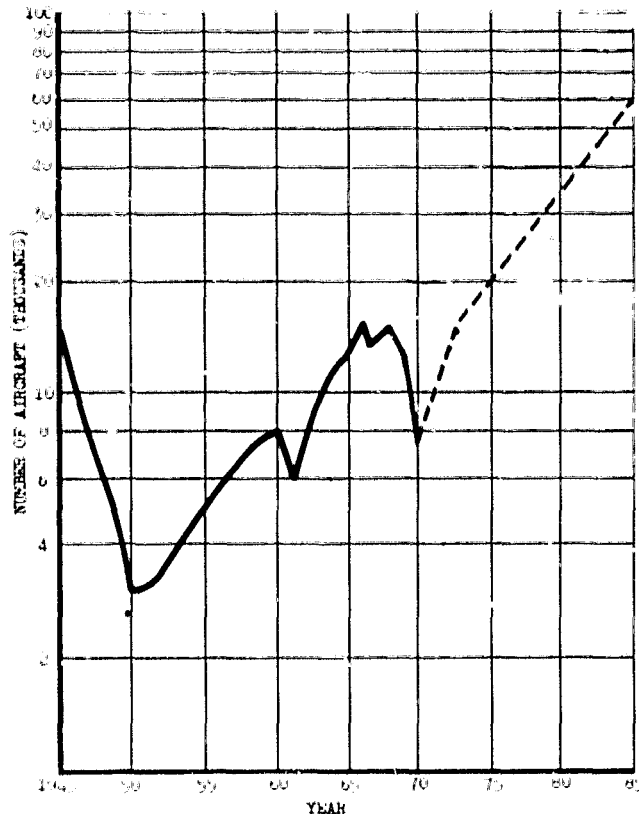
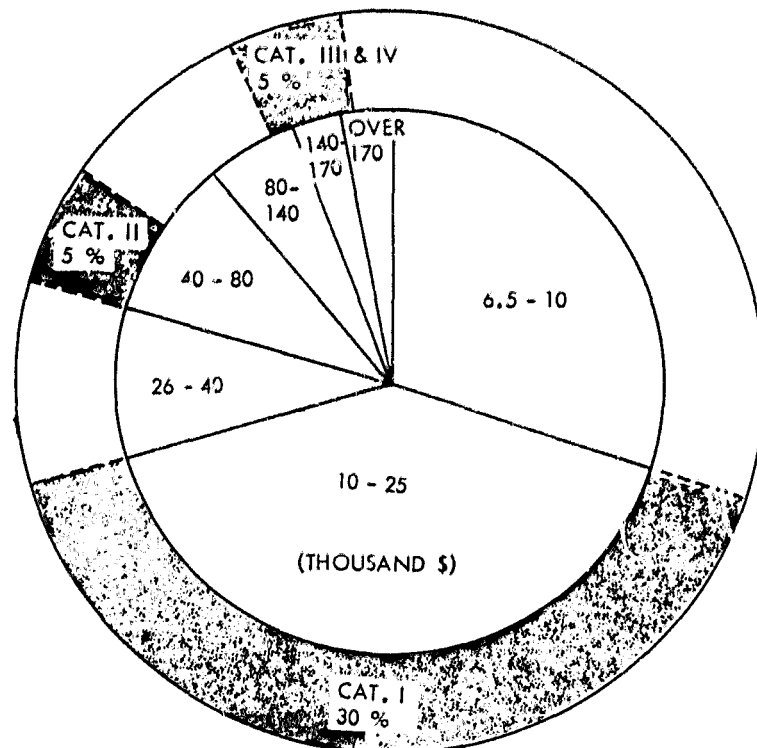


FIGURE 1.10.2

PRICE CLASSIFICATIONS OF GENERAL AVIATION AIRCRAFT DELIVERED IN 1969 AND THEIR RELATIONSHIP TO CATEGORIES I, II & III, IV

(EXCLUDING AVIONICS)



1.10 Projection of 1985 General Aviation Use Potential

1.10.1 Price/Quantity Relationship

For the aircraft derived in this study, the effect of yearly production quantity on price was discussed in Section 1.8.16 and illustrated in Figure 1.8.23. This section attempts to analyze the effect of price on marketable quantities. This is an example of the "chicken and egg" question - which comes first, price or quantity? Even if aircraft were sold in comparable quantities to automobiles, their higher cost-per-pound (by a factor of about 6) would cause their unit cost to exceed that of medium priced automobiles by a factor of about 2.8. While even this relationship would stimulate the market, a yearly quantity of 100,000 for a single model would represent about one-third of the entire fleet forecasted for 1985, hence is highly optimistic. The annual delivery rate, projected to 1985, was derived from Ref. 1.7 and is shown in Figure 1.10.1. Despite the recent recession, the production rate for all aircraft might reach 60,000 by 1985.

Figure 1.10.2 shows a breakdown into price groups and the relationship to aircraft in Categories I, II, III and IV. These combine to represent 40% of the total general aviation market by number of aircraft, with Category I accounting for 30%, Category II accounting for 5%, and Categories III and IV combined representing 5%. Applying these percentages to the 60,000 per year forecast for 1985, we can foresee 18,000 in Category I, along with 3000 in Category II, and 3000 in Categories III and IV combined. By reference to Figure 1.8.23, and assuming 1 model in Categories I and II will account for one-third of the total, we can establish price tags of \$11,000 for Category I and \$39,000 for Category II. Assuming Categories III and IV split their share of the market and a specific model of each category will account for one-third of the sales, would indicate a production rate of 500 vehicles. This gives a selling price of \$153,000 for Category III and \$130,000 for Category IV.

1.10.2 Growth Constraints

The growth in general aviation aircraft deliveries forecasted for the 1970-1985 period represents a potential which is unconstrained by adverse factors. Warnings, however, have been given citing forces at work which could reduce this potential to a much smaller figure. The principal constraints appear to be declining utilization, insufficient emphasis on education, airport saturation and air traffic regulations.

With regard to utilization, the average yearly figure for all pilots is about 130 hours. Figure 1.7.4 showed a rapidly increasing cost of operating any aircraft less than 300 hours per year. New uses must be found for, and greater convenience must be designed into, personal aircraft. Business aircraft must be designed for increased schedule availability, and some should have the ability to use close-in airfields. Noise and pollution objections must be overcome. The growth of business flying during the 1960's was less than that of the GNP, which is an indication of utilization far below its potential.

The subject of education includes attracting new pilots in growing numbers, showing business managers how they can operate aircraft profitably, and promoting safety features. Even with increased utility and educational programs, the potential growth of general aviation can be hamstrung in the future by airport saturation. Surveys show that only 7,000 airports in the U.S. are available to the public and that at least a 33% increase is required before general aviation can begin to realize its growth potential. Inexpensive, unpaved airstrips, located close to residential and business areas can partially fill the gap, provided that aircraft with low noise levels, minimum air pollution and high flotation landing gear are made available. The adoption of the air cushion landing system would make waterways available as well.

Air traffic regulations, governed by the FAA, are becoming more complicated with the increase of traffic density, particularly within metropolitan areas. Air traffic control must move in the direction of simplicity, otherwise existing and potential pilots will lose their initiative. Stricter pilot licensing requirements will have a similar effect. Safety must be promoted by educational processes rather than regulatory complexity.

1.11 Conclusions

1.11.1 Specific Conclusions

Category I aircraft which are directed toward individual and small business ownership, must be designed primarily for a combination of high utility and low price. Foldable wings are recommended for home storage and roadability and the air cushion landing system for all-terrain operation. Their external noise level should not exceed 75 PNdB at 500 ft. and their internal noise level and visibility can be optimized with a pusher propeller installation. Their field length should not exceed 1,500 ft., their cruise speed should be close to 150 knots, and their range not less than 400 miles. As in the case of the other three categories, the rotating combustion engine appears to be the ideal power plant.

Category II aircraft are intended for STOL operation in and out of close-in airfields, and are directed primarily toward business ownership. It is therefore necessary to provide high cruise speed (200 knots minimum), adequate range (500 miles minimum), 1000 ft. maximum field length and not over a 75 PNdB noise level at 500 ft. Schedule reliability should be provided by the installation of advanced avionics, with IFR capability automatic flight control and extra safety provisions. A high level of comfort should be provided by use of vibration-free rotating combustion engine, pusher propeller and cabin pressurization. This type of airplane can be priced at about \$50,000.

Category III aircraft are intended for use by the small to medium business owner primarily for long range, intercity operation. This requires a minimum cruise range of 1,500 miles, and a minimum cruise speed of 250 knots. Operation from 2,000 ft. airfields, with a maximum exterior noise level of 85 PNdB at 500 ft. is considered feasible. Cabin pressurization, advanced avionics, automatic flight control and extra safety provisions are recommended. The configuration can take two forms: a high wing twin engine - propeller or a single turbofan engine installation, with the price tag held in the range of \$150,000 to \$200,000.

Category IV aircraft comprise the VTOL segment of general aviation, directed primarily for business use because of cost considerations. They are intended for operation primarily within metropolitan areas, hence speed and range requirements should be subordinated to more necessary features. The helicopter should continue to play this role, since fixed wing VTOL concepts appear too expensive for general aviation. The 75 PNdB noise level is maximum for downtown operation and is not penalizing. Advanced avionics, automatic flight control and extra safety features are recommended for maximum utilization. Cruise speed can be as low as 135 knots and a range of 250 miles with full payload might be adequate. This combination will hold the price to around \$200,000, resulting in a substantial, but relatively low volume, market.

1.11.2 General Conclusions

The impact of advanced technology can improve the utility, dependability and safety of general aviation aircraft, while simultaneously lowering initial and operating costs. This area includes aerodynamic design, propulsion systems, avionics, structural design, safety provisions, special utility and convenience features and V/STOL technology. The most promising lines of development include quiet propellers, the rotating combustion engine, the air cushion landing system, the use of low cost composite materials and associated processing, and the development of low cost, reliable avionics. Improved handling qualities though not specifically address in this study should be sought by continued research and development.

Environmental factors, which include pollution of the air by noise and noxious gases, will constrain the growth of general aviation by regulatory processes unless the industry will face up squarely to the problems. The noise problem can be solved without serious penalty, as shown in this study. Pollution control is receiving widespread attention by the engine manufacturers and is expected to reach a satisfactory level by 1975.

Educational programs must be increased in tempo. These include the acceleration of pilot training, the economics of business ownership and convincing the public of the safety and environmental compatibility of general aviation aircraft.

Airfield and service facilities must be increased to sustain the growth of general aviation. Convenient locations must be emphasized. Government financial aid to small and large communities is necessary. Such aid can be tied in with noise and air pollution standards.

Federal Air Regulations must be tailored to promote the growth of general aviation, while maintaining a high standard of safety. Traffic regulations need to be simplified, rather than complicated. Higher standards for handling qualities should be established, applicable to all general aviation aircraft.

FIGURE 1.12.1

RECOMMENDED AIRCRAFT R&D AREAS

- o STRUCTURAL DESIGN STUDY OF A REPRESENTATIVE AIRPLANE, USING COMPOSITE MATERIALS
- o DETAILED STUDY AND ACTUAL INSTALLATION OF AN RC ENGINE, DRIVING A QUIET PROPELLER
- o IMPROVED HANDLING QUALITIES PROGRAM FOR A REPRESENTATIVE AIRPLANE, PHASED INTO STUDY, WIND TUNNEL TEST, SIMULATION AND FLIGHT TEST
- o SEPARATE DETAILED STUDIES TO INCLUDE
 - A CONTROL-CONFIGURED AIRPLANE
 - APPLICATION OF THE AIR CUSHION LANDING SYSTEM
 - VTOL AND STOL APPLICATIONS
 - TURBOFAN VS. PROP-FAN

FIGURE 1.12.2

RECOMMENDED PROPULSION AND AVIONICS R&D AREAS

PROPULSION

- o DEVELOP, TEST AND CERTIFY A ROTATING COMBUSTION ENGINE WITH NOISE AND EMISSION CONSTRAINTS
- o DEVELOP, TEST AND CERTIFY A LOW NOISE LEVEL PROPELLER DESIGNED FOR LIGHT WEIGHT AND LOW COST.

AVIONICS

- o FOLLOW UP STUDY OF CONTROL-CONFIGURED AIRPLANE WITH DEVELOPMENT OF APPLICABLE EQUIPMENT FOR FLIGHT RESEARCH.

1.12 Recommendations1.12.1 Recommended Aircraft R&D Areas

The first concern is the provision of support in the development of usable advanced technology. The prime areas listed in Figure 1.12.1 comprise an initial approach to the development of better aircraft. Hopefully, the results will generate further R&D effort, which the industry will use to best advantage.

The first item suggests a study similar to the previous one by San Diego Aircraft Engineering but making economical use of more advanced composites and confining the study to one particular model. The second study item would also utilize advanced technology in both the engine and propeller and would also be confined to one particular aircraft. This would follow a current effort along this line. In the third item, it is recognized that considerable effort is being directed toward improving the handling qualities of small aircraft. This recommendation, however, would project the study toward full utilization of advanced technology.

The last block includes several items. The study of a control-configured airplane implies the use of an automatic flight control system, with attendant avionics in an effort toward achieving all-weather flight capability. The study of an air cushion landing system application would pick up the existing technology and project it into the 1980's. The V/STOL applications would be directed toward recommending optimum configurations for the missions. Finally, the turbofan and prop-fan propulsion systems would be optimized for comparison with the engine-propeller configuration.

1.12.2 Recommended Propulsion and Avionics R&D Areas

Aircraft development, in itself, is not sufficient, and parallel efforts must be made in related fields. Two of the most important are the areas of propulsion and avionics, as listed in Figure 1.12.2.

FIGURE 1.12.3

GENERAL AVIATION NON-TECHNICAL CONSTRAINT STUDIES

- o AIRFIELD AND SERVICE FACILITIES SURVEY AND ORDERLY EXPANSION PROGRAM
- o FEDERAL AIR REGULATIONS, AS AFFECTED BY EMERGING TECHNOLOGY, TRAFFIC DENSITY, ENVIRONMENTAL CONSIDERATIONS, ETC .
- o LICENSED PILOT AVAILABILITY SURVEY, FORECAST AND EDUCATIONAL PROGRAMS
- o GENERAL FORECAST FOR GENERAL AVIATION, TO 1985, ASSESSING THE IMPACT OF ALL PERTINENT FACTORS.

Propulsion development must be directed toward penetration of the cost, noise, and pollution barriers. Since the rotating combustion type of engine appears to be a clear choice for general aviation aircraft of the future, it requires detailed development for this application. The power rating of the engine can be determined by assessing the most popular category of aircraft in which it would be used - probably Category I of this study. The propeller would be designed for the same application.

Avionics development must be aimed at lower cost, greater capability, and higher reliability. The control-configured airplane would evolve from the previously suggested study, but an available airplane with similar flight characteristics could be used for flight research.

1.12.3 General Aviation Non-Technical Constraint Studies

No matter what degree of technical improvement can be achieved in aircraft and related systems, there are other areas which must be addressed if general aviation is to have substantial growth in the future. These areas have been previously discussed, and Figure 1.12.3 lists some definite action which can be taken to provide support. The last item would be timed to follow the technical studies and the foregoing areas listed above.

References

- 1.1 Drake, H. M., Kenyon, G. C., and Galloway, T. L.: "Mission Analysis of General Aviation in the 1970's," AIAA Paper 69-818, July 1969.
- 1.2 Anon: "Potential Structural Materials and Design Concepts for Light Aircraft," San Diego Aircraft Engineering, Inc., NASA CR-1285, March 1969.
- 1.3 Hurkamp, C. H., Johnston, W. M., and Wilson, J. H.: "Technology Assessment of Advanced General Aviation Aircraft" (Final Report), Lockheed-Georgia Company, NASA CR-114339, June 1971
- 1.4 NASA Ames Research Center, Contract NAS2-5972: "Technology Assessment of Advanced General Aviation Aircraft," June 15, 1970.
- 1.5 Worchel, R., and Mayo, M. G.: "Advanced General Aviation Propeller Study," Hamilton Standard Division of United Aircraft Corporation, NASA CR-114289, April 1971.
- 1.6 DOT/FAA Office of Policy Development: "General Aviation Operation Costs," February 1969.
- 1.7 R. Dixon Speas Associates, "The Magnitude and Economic Impact of General Aviation, 1968 - 1980," Report for GAMA, 1969